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ANALYSES OF WIND EROSION PHENOMENA IN ROOSEVELT AND CURRY COUNTIES, NEW MEXICO

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ANALYSES OF WIND EROSION PHENOMENA IN ROOSEVELT AND CURRY COUNTIES, NEW MEXICO[1/]

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During March of 1952 drought and winds combined to produce a number of dust storms in an area in western Texas and eastern New Mexico. In an effort to secure a better understanding of conditions, arrangements were made to carry out a series of field tests and studies in Roosevelt and Curry Counties, New Mexico.

Participating in the investigation were Soil Conservation Service personnel of research and operations offices serving the area and the New Mexico A.& M. College. Fields were selected for study by the operations group and portable equipment was brought from the wind erosion laboratory at Manhattan, Kansas, to the SCS district office headquarters at Portales, New Mexico. The field work was completed during an 8-day period, April 9-16, 1952.

Methods of study comprised (1) analysis of climatic data; (2) erodibility tests made by using a portable wind tunnel on farm lands; (3) tests of the erodible characteristics of soils made by semi-portable wind tunnel methods; and (4) analyses of soil characteristics related to erodibility by wind. Analytical work and the assemblage of experimental data into report form were performed at the research headquarters at Manhattan.

1/ Joint contribution from the New Mexico Agricultural Experiment Station; Wind Erosion Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering; and contribution no. 484, Department of Agronomy, Kansas Agricultural Experiment Station.

2/ Project Supervisor, Agent, and Agricultural Engineer, respectively, Division of Soil Management in the Irrigated and Dry Land Region, BPISAE, USDA. Affiliated with the Research Division of the Soil Conservation Service prior to November 1952.

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General Description of Area

The lands of Roosevelt and Curry Counties are a portion of the High Plains and lie at an elevation of approximately 4,000 feet. The average annual precipitation ranges from 15 to 18 inches, increasing across the area from west to east.

The soils studied belong to the reddish-brown and reddish-chestnut soil zones and comprise the Amarillo, Dalhart, Church, Pullman, Arch, and Portales series. Both high-lime and low-lime soils are represented. The texture of the soils ranges from loamy sand to clay loam. The vegetation of the area was originally short grass or plains grassland.

Maker and Dregne (7) have divided the area into climatic zones designated as 3 and 4 on the basis of precipitation and temperature. The maximum land capability class of climatic zone 3 is assumed to be class III. The maximum capability of the lands of zone 4, having the more hazardous climate, is class IV.

Winter wheat, grain and forage sorghums, sudan grass, and broom corn are the main crops grown in the drylands of the area. For New Mexico as a whole the acreage seeded to winter wheat has more than doubled in the decade 1940-1950. Most of this expansion has been in the eastern portion of the state. While accurate figures are not available, at least a 5-fold increase has occurred in Roosevelt County during the same period. This expansion of cultivated land accompanying the plow up of grass lands parallels conditions experienced in portions of western Texas, eastern Colorado, and western Kansas during the past decade of favorable weather and high demand for crop products.

Procedure

Analysis of Climatic Data

Due to the general limited nature of wind records, analysis of climatic data from only one location was made. Published wind, temperature, evaporation, and precipitation data were all available from the Weather Station, 7 miles northwest of Portales. These data cover the period 1935-1952. The seasonal patterns of precipitation and wind, intensity-frequency of wind movement, and combinations of rainfall and wind movement were studied.

Selection of Sites

A map of Roosevelt and Curry Counties is shown in Figure 1. Given on the map are locations of the 19 fields chosen for both portable and semi-portable wind tunnel study. A number has been assigned to each of these primary sites and the name of the owner or operator is

given. The order of numbering sites is related to the textural classification of the soils into a grouping as follows:

Site Number	Textural classification
1 - 5	3 loamy
6 - 15	4 sandy
16 - 19	5 very sandy

An attempt was made to select fields that had not been disturbed by recent cultivation. This condition prevailed generally in fields of sorghum, sudan grass, and broom corn stubble. A few exceptions to provide widely contrasting conditions in residue cover were made. Five secondary sites 20 - 24 were selected for semi-portable wind tunnel studies of the effects of deep plowing and other factors. Data pertaining to these five locations are given in Table 1.

Portable Wind Tunnel Operations

Single wind tunnel tests were made on each field. While past experience has indicated that considerable sampling variability exists, it was believed that the large contrasts between fields did not warrant repeated tests to gage the more important differences.

The procedure of tunnel operation was modified somewhat from that used in the past. A considerable time period (roughly 1 to 2 hours) would have been required for erosion to cease on the more erodible fields for a given force as applied by the tunnel. The tunnel was operated, therefore, with a constant velocity of 38 miles per hour in the center of the 3-foot-square duct. The weight of soil removed at the end of 5-, 15-, 30-, and 45-minute time periods was determined. The total was estimated from the extrapolation of the trend line of soil loss with time.

The wind force on test surfaces of different roughness is a variable for a constant velocity at a given height in the confines of the duct. For example, it was equivalent to 2,250 pounds of surface drag per acre on the smoothest field surface and reached a maximum of 5,200 pounds per acre on the roughest surface. It has been estimated (9) that a surface drag of 3,000 pounds per acre approximates a value associated with an average atmospheric wind expected to occur at one to two year frequency intervals in the High Plains.

The amount of removal of soil by wind occurring before a surface becomes stabilized (6) has been found to vary with the surface drag to the 2.5 power. This power function of soil loss with surface drag was used to adjust all losses to a common wind force level of 3,000 pounds per acre.

Quantitative determinations of the residues present on the surfaces of the fields were made by triplicate sampling. The material

present on meter-square areas near the tunnel test sites was picked up by hand for subsequent weighing.

Surface roughness plays a part in the erodibility of a field surface in addition to the variables of residue and clod structure. A parameter called the "ridge roughness equivalent" was determined, therefore, for each surface. This parameter gives roughness in terms of the height of gravel ridges having a height-spacing ratio of 1 to 4. It is determined for a given surface from pressure relationships found in the tunnel by prior laboratory calibration (11).

All tests on sorghum stubble were made with the wind applied at right angles to the row direction. Previous studies (12) of the effect of wind-row orientation on erodibility of land in sorghum stubble have demonstrated that greater losses would have been obtained had the wind been applied parallel to the row direction.

Semi-portable Wind Tunnel Procedures

In addition to its use on the surfaces of fields, the portable wind tunnel was located subsequently on a city lot in Portales. A level surface of nonerodible lime "chat" was placed to form the floor of the tunnel duct. Trays 5 feet long, 8 inches wide and 2 inches deep, with open ends were placed level with the "chat" surface near the leeward end of the 30-foot tunnel. Samples of soil were placed in the trays in the manner normally followed in the stationary tunnel at the Manhattan headquarters. The surface in the trays was leveled as uniformly as possible and exposed to wind until soil removal ceased. The wind velocity was 25 miles per hour at 6 inches above the soil sample. The drag velocity was estimated to be about 40 cm. per second, which is equivalent to a surface drag of 276 pounds per acre.

Method of soil sampling and analysis

Composite samplesof about 20 pounds or more from various depths were obtained from selected areas in the 24 fields. The soils were sampled only when reasonably dry. They were transported to Portales in shallow trays, thoroughly air dried, dry sieved, and tested for erodibility in the semi-portable wind tunnel installation. Smaller samples were transported to the wind erosion laboratory at Manhattan, Kansas, for other determinations.

The size-distribution of dry aggregates or clods was made by the use of a rotary sieve used regularly in this work (2). Duplicated sievings of samples into seven size-fractions were performed shortly after they were obtained from the field.

Mechanical stability, that is, the relative resistance of clods to breakdown by mechanical forces such as sand abrasion or cultivation, was determined by repeated dry sieving (4). The mechanical stability is a relative measure of coherence or strength of cementation of aggregates in

a dry state and, as used in this work, is equal to 100 $\frac{W_1}{W}$ where W is the weight of aggregates greater than 0.84 mm. after the first sieving and W_1 is the weight of these aggregates after the second sieving.

Mechanical composition, or the proportionate amounts of sand, silt, and clay, were determined by the latest method of Bouyoucos (1). The textural class for each site is based on these determinations. The soil unit designation was made in accordance with "Guide for Mapping, Soil Conservation Surveys, Region 6," dated 2/3/47.

The size distribution of water-stable particles was determined by the Yoder method modified in accordance with the latest Soil Conservation Service recommendations.

Results

Climatic Factors

Precipitation and wind pattern.--The average pattern of wind movement and precipitation by calendar months is shown in Figure 2.

The location has a 6-months rain period beginning in May and extending through October. On the average, 82.5 percent of the total annual precipitation falls in this period. Again, the 6-months period January-June may be described as the season of winds. The peak of wind movement occurs in March, although April has only slightly less wind intensity.

The occurrence of the highest winds near the end of the dry season means that any cultivated soil surface not protected by residues held over from the previous fall, or by an adequate cover of winter wheat, will ordinarily be dry and subject to movement.

Records indicate a wind movement of 5.4 miles per hour during the month of March. This contrasts with a minimum of 2.5 during the low period in August. The significance of this difference is great. The power of the wind varies as the cube of the wind velocity. The relative ability of winds for the two periods to move soil is, therefore, equivalent to $\left(\frac{5.4}{2.5}\right)^3 = 10$. That is to say, March winds on the average have 10 times as much power as August winds.

<u>Rainfall, wind velocity, and erosion index</u>.--The average March and April wind velocities recorded at the N.W. Portales gage over the period 1935-52 are shown in Figure 3. The year 1935 had the highest recorded wind movement. Wind movement at the relatively low average level of 4.6 miles per hour occurred during the decade starting in 1940. The average for the last 3-year period has been 5.1 miles per hour which is not greatly above the low 10-year average. It is, however, still substantially below the "dust bowl" conditions of winds existing in the middle thirties.

A plotting of the annual amounts of precipitation for the period

1935-52 is shown also in Figure 3 along with March and April wind movement. Total precipitation of 9.5 inches, occurring in 1951, was the lowest of the 17-year period of record. The extreme variability of the climate is indicated by the 54.6 inches of rainfall recorded in 1941. The median amount of precipitation for the period has been 16.70 inches.

Combinations of drought and high winds are the major climatic hazard with respect to the wind erosion problem in a given area. Where cultivated crops are grown, drought may result in little or no vegetative growth. Depletion of residue covers and consequent exposure of the soil make the surface vulnerable to winds. Upon occasion, the winds do not materialize; however, high spring winds usually follow a dry year.

A combination of wind movement and precipitation, $\frac{u^3}{P1}$, where u is the average March and April wind velocity for a given year, and P1 is the previous year's rainfall, appears to provide a reasonable index to the wind erosion hazard. The plotting of this index is shown in Figure 3. This index reached a high in 1935 and then decreased rapidly. Substantial rises in the index occurred in 1941, 1944, and 1952. Assuming the records to be a true representation of fact, the current situation is much less severe than conditions of the thirites. This is due primarily to the fact that winds have been only about average.

Intensity-frequency of wind movement.--High winds have the property of chance occurrence in nature. Previous studies (10) have shown that wind movement data may be fitted into probability series and its recurrence interval estimated. Figure 4 shows the velocities expected at the Portales gage location for duration-periods of 1, 3, 7, and 31 days for the month of March. For example, the graphs indicate wind velocity levels at 5- and 50-year recurrence intervals as follows:

Duration period	Recurrence interval 5 years	Recurrence interval 50 years
days	mph	mph
1	19.9	30.0
3	12.5	18.0
7	9.8	14.0
31 (Average for month)	6.2	8.1

Field Tests

Photographs of the portable wind tunnel and each of the nineteen fields tested are shown immediately following the text. Accompanying each photograph is information relating to location, ownership, soils, crop cover, and residue. The conditions of the immediate surface govern the losses by wind and are given, therefore, in considerable detail. The values given for mechanical analyses and the percent of soil material less than .42 mm. in diameter are from the surface inch of soil. Marked contrasts in the erodibility of the several field surfaces are apparent. These losses range from 0.062 to 230.0 tons per acre.

<u>Relationship of soil eroded to surface factors</u>.--Soil removed at a constant force level of 3,000 pounds per acre is primarily a function of crop or residue cover, roughness of the surface, and the size fractions of the soil forming the surface. The use of multiple regression methods to determine this relationship, using data from all fields, resulted in the following estimating equation:

$$\log x = -8.96957 + 7.33294 \log A - 1.17067 \log RK$$

where x is the loss of soil in tons per acre, A is the percent of soil particles smaller than 0.42 mm. contained in the surface inch of soil, R is the weight of surface residue in pounds per acre, and K is the ridge roughness equivalent of the surface in inches. The correlation of the expression is 0.834, which means that approximately 70 percent of the variability of soil loss is accounted for by the relationship. Since mathematical equations are not easily understood, a graph of the relationship is presented in Figure 5.

Referring to Figure 5, it is readily seen that soil loss increases greatly with "A", the percentage of relatively small soil material present. It decreases with values of "RK", the product of the weight of residue and surface roughness. Geometric means of the percent A fraction and the product RK for a grouping of the fields into soil textural classes are shown also in Figure 5. Since the factors bear an exponential relationship to soil loss, the geometric mean (obtained from the average of the logarithms of each factor) is the best measure obtainable of the "average condition." Pertinent data relating to these averages are as follows:

Textural group	"A" fraction	Weight of residue	Value of RK	Loss by wind From equation	Loss by wind Measured
No.	%	Lb./A.	Lb.Inches/A.	Tons/A.	Tons/A.
3	68.9	875	2923	3.0	2.0
4	77.2	560	2529	7.5	8.7
5	92.3	400	1361	59.0	66.8

From the above table it appears that on the average the product RK decreases, or less residues and roughness are present, as we go to the soils of a more erodible nature. The soil losses from the three groups are in the ratios of approximately 1:3:25.

The use of Figure 5 to estimate losses is dependent on a measurement of the percentage of the A fraction. This can be accomplished by a simple screening of soil material from a field surface. The value of R, the weight of surface residue, is also relatively easy to obtain. The value of K, however, comes from wind tunnel calibration and is a combination of several variables. The mechanical configurations, such as ridging, are a part of the roughness; also, the nature of the residue or cover influences the value of K.

In general, the roughness of a field surface increases with the weight of residue. This relationship is shown in Figure 6. The roughness of the listed surface, Site 9, has little relationship to the weight of residue present. The remaining sites follow the general trend fairly well. The leafy sorghum residue usually has a greater roughness than the stubble that has lost its leaves. Several differences in protective cover or surface roughness, in addition to their weight and the height-equivalent of the roughness, are apparent. For equal weight of residue, wheat stubble is more effective than sudan grass. Again, sudan grass is more effective than grain sorghum.

Rating of surface and cover conditions.--The influence of residues and roughness in reducing losses by wind is brought out clearly in Figure 7. In this figure, losses from all sites as measured by the wind tunnel are plotted with respect to the percentage of the A fraction. The loss from an approximately bare soil condition may be calculated from the regression equation by assuming the roughness K to be equal to 2 inches and the amount of residue R to be equal to 100 pounds per acre. These are approximate minimums obtained in the field as will be noted from the average relationship of K to R in Figure 6. This procedure yields the upper line of the figure where losses range from 23 tons per acre for a value of A = 60 percent to about 500 tons per acre where A = 90 percent. The plotted points fall considerably below the trend line of losses estimated for the approximately bare and smooth soil surface. The difference between the line and the plotted points represents the lowering of the regimen of soil loss by the residue and roughness present on the fields.

A roughness and cover index for each field may be obtained from Figure 7. This is determined for a given field by computing the ratio of loss from the line to the measured loss indicated by the plotted point. Both values of loss would be for the same value of A. Values thus obtained represent the magnitude of the reduction due to surface conditions other than soil structural properties. Table 2 lists the site number, soil textural class, estimated loss from the line of Figure 7, the loss as measured by the wind tunnel, and the roughness and cover index for each field. It will be noted that the values of the index range from 2 to 1,210, or, in other words, the surface and cover condition has reduced the loss from $\frac{1}{2}$ to $\frac{1}{1210}$ of that estimated for minimal roughness and residue conditions approximating an open soil.

More or less arbitrary ratings of surface and cover conditions are designated into broad groups as follows:

Surface and cover conditions

Value of index	Rating
0 - 10	Poor
10 - 100	Fair
100 - 1000	Good
Over 1000	Excellent

Thus, a "poor" surface and cover rating is one able to reduce losses by 0 to 10 times, while an excellent one must be capable of reducing the magnitude of loss by more than 1,000 times.

The descriptive ratings for the fields are shown in Table 2. Given also are the ratings that would be required to reduce the regimen of losses below given arbitrary amounts of 1 and 5 tons per acre. Illustrative example:

The rating required to reduce the loss from Site 1 to less than 1 ton per acre is derived as follows:

$$\frac{\text{Estimated loss}}{\text{Required loss}} = \frac{75}{1} = \text{index of } 75$$

The value of 75 lies in the upper range of the "fair" condition. A general surface condition and cover rating of "good," where the losses are reduced 100 to 1,000 times, would be required to assure that the field would yield losses of less than 1 ton per acre.

From a study of the ratings listed in Table 2, it will be noted that only Site 1 had surface protection adequate to assure losses below the 1 ton per acre level. Four sites, numbers 1, 4, 9, and 14, had cover ratings adequate to reduce losses to less than 5 tons per acre. In general, the following condition prevails:

Soil texture class	Surface condition and cover rating	
	Existing	Required to assure less than 5 tons/A. loss
3	Poor - Excellent	Fair - Good
4	Poor - Good	Good
5	Poor - Fair	Good - Excellent

Existing conditions as shown by the ratings range from poor to excellent on the soils of Number 3 texture. This wide range reflects in great measure the management to which soils have been subjected and indicates that with proper management the required fair to good condition is obtainable readily. For the soils of Number 4 texture, better than average management is necessary to maintain good protection. With soils of Number 5 texture only poor to fair conditions were found in the field. The required good to excellent conditions appear to be beyond the reach of management of the land in row crops under climatic conditions prevailing in 1951-52. Under properly managed native vegetation or grasses the soils of Number 5 texture undoubtedly had "excellent" cover ratings. Their use under permanent vegetative cover appears to be desirable and is possibly necessary for stable land use.

Soil Characteristics

Detailed data obtained from this study are included in Tables 3 and 4. To show more clearly the effect of the various factors on soil erodibility, figures have been prepared based on Table 3.

Relation of erodibility to soil cloddiness.--There was a close association among the degree of cloddiness, the proportion of highly erodible fraction A (less than 0.42 mm. in diameter), the proportion of highly and semi-erodible fractions A and B (less than 0.84 mm. in diameter), and the measured erodibility of the three textural classes analyzed. Clod structure, sometimes referred to as a dry aggregate structure, was a primary factor governing erodibility by wind. The data show that the most cloddy soils had the lowest proportion of fractions A and B and, therefore, were least erodible. On the other hand, the least cloddy soils had the highest proportion of fractions A and B and therefore were most erodible.

The erodibility was associated with the proportion of erodible fractions but no simple expression would fit the whole range of values. Figure 8 shows the erodibility based on the amount of fraction A contained in the soil. Figure 9 indicates the relationship between erodibility and the proportion of fractions A and B. The magnitude of deviation of individual values of erodibility from the mean values is about the same as where erodibility was plotted against fraction A alone. Evidently, either the amount of fraction A alone or the amount of fractions A and B together, as determined by dry sieving, can be used as an index of erodibility. These simple indexes have been used successfully in previous evaluations of erodibility (4,8). Although they are not the only primary factors influencing erodibility they are by far the most important (3). The influence of factors other than fractions A and B is to some degree cancelled out by opposing trends and by relatively large inherent errors of estimation. These minor factors are the primary reason for a certain amount of deviation of individual values of erodibility from the average values, as shown in Figures 8 and 9. Despite some error of estimation it appears possible to determine by dry sieving the approximate relative erodibility of soils by wind. The equipment necessary would be a 0.42 or 0.84 mm. sieve and the use of a graph such as Figure 8 or 9.

It is shown in Figures 8 and 9 that a negligible amount of erosion (0.1 ton per acre)occurs when the soil contains about 30 percent of the fraction smaller than 0.42 mm. in diameter or about 40 percent of the fraction smaller than 0.84 mm. in diameter. Soils containing less than these amounts of erodible fractions may be considered non-erodible.

The influence of depth on clod structure and erodibility.--Cloddiness increased appreciably with depth in all soils studied. The amount of erodible fraction less than 0.84 mm. in diameter decreased with depth (Figure 10). The erodible fraction decreased to 40 percent at a depth of $3\frac{1}{2}$ inches in loam and clay loam soils, at about 6 inches in sandy loam, and at 11 inches in loamy sand. Loamy sand would have to be plowed much deeper than sandy loam, and sandy loam, with some exceptions, much deeper than loam to produce equal cloddiness of the surface soil.

Soil erodibility decreased with depth even more rapidly than the amount of erodible fractions (Figure 11). This is because erodibility varies as some power of erodible fraction. Figures 8 and 9 show that erodibility varied as the 3d to the 8th power of the percentage of erodible fractions.

Variation in soil texture with depth.--The percentage of clay increased and the percentage of sand decreased with depth in all soils studied (Figure 12). Below the cultivated zone an increase of clay with depth is due to the well known illuviation and weathering processes. Within the cultivated zone, however, the texture would be uniform if no erosion occurred. In almost every field that had not been cultivated and that blew during and prior to the wind tunnel tests in the spring of 1952, a thin mantle of soil much coarser than that below was found. Silt and clay blew away, and sand lagged behind. This sorting action is extremely harmful in dryland areas, especially on coarse-textured soils. Wherever cultivation was performed, the mantle of sand was buried, some clods were brought to the surface, and erosion was decreased at least temporarily.

The influence of soil texture on clod structure and erodibility.-- The percentage of erodible soil fractions varied inversely as the percentage of clay (Figure 13). Thus loamy sand with least clay had the largest proportion of erodible fractions; sandy loam had more clay and therefore less erodible fractions; loam and clay loam had the highest content of clay and, therefore, the lowest proportion of erodible fractions. The data of Figure 13 are based on conditions in the first inch of soil. Similar comparisons at lower depths could not be made because the depth of sampling was not uniform throughout the whole study.

The percentage of erodible fractions as shown in Figure 10 decreased with depth. The clay content, as shown in Figure 12, increased with depth. Figure 13 shows further that an increase in clay is associated with a decrease in erodible fractions. It is evident from these data, however, that a decrease in erodible fractions with depth is not due altogether to the increase in clay content. Soils of exactly the same texture had a much higher proportion of erodible fractions near the surface than at lower depths. It is evident, therefore, that increased cloddiness with depth is due in great measure to force of compaction. The lower the depth, the greater is the degree of compaction, the less the degree of disintegration of structure by forces of the weather, and the less is the proportion of erodible fractions.

The data of Figure 13 are based on the conditions of the surface soil after considerable sorting by wind had occurred. Thus, some sandy loams had soil on the surface that was definitely a loamy sand, whereas the loams and the clay loams had, in many cases, a surface mantle composed of a sandy loam. These marked changes in the surface soil texture were due to several dust storms occurring principally in the spring of 1952.

A positive relationship was found between soil erodibility and the clay content (Figure 14). By extrapolation of Figure 14 it will be seen that the clay content of the soil would have to be increased considerably above 20 percent before erodibility would be decreased to a negligible amount of, say, less than 0.1 tons per acre.

The influence of depth and soil texture on mechanical stability of clods.--The ability of clods to resist breakdown by mechanical forces, known as mechanical stability, varies directly with the ability of the clods to resist disintegration by abrasive action of drifting soil. The abrasive action of wind erosion is one of the most serious aspects of erodibility by wind. Hence, it was decided in connection with this study to determine the mechanical stability from which some idea might be obtained of the relative abradability of the aggregates at various depths and on different soils.

Mechanical stability of aggregates greater than 0.84 mm. in diameter increased with depth on all soils (Figure 15). Mechanical stability also increased with the fineness of soil texture, that is, with percentage of clay. Thus, the coarsest soil, loamy sand, had the lowest mechanical stability and clay loam the highest at corresponding depths.

The clay content, as shown previously, increased with depth, and it is apparent that the increase in mechanical stability with depth is due, at least in part, to increased clay. The data show, however, that the increase in mechanical stability with depth was not due entirely to the increase in the percentage of clay. Thus, on Sites 1, 4, 13, 16, and 21, the percentage of clay was less at lower depths than near the surface, yet the mechanical stability of the aggregates invariably increased with depth (Table 3). The increase in mechanical stability with depth is apparently also associated with the degree of soil compaction. The lower the depth the greater the compaction and the greater the mechanical stability of the clods.

The influence of lime on soil structure and erodibility.--An accurate evaluation of the influence of free calcium carbonate, or lime, on soil structure and erodibility is extremely difficult to make in the field. This is because it is almost impossible to choose two sites exactly alike in texture, etc., but varying in lime. The lime itself has some influence on soil texture. The lime crystals when immersed in water are predominantly of the size of silt. Over 99 percent of these crystals exceed 0.002 mm. in diameter.

The effect of free calcium carbonate (as opposed to that tied up in the cationic exchange complex of the colloidal fraction) is perhaps largely physical and is probably the same as that of similar sized particles of quartz silt. A previous study (5) has shown that silt, being a mild cementing agent, mainly is responsible for cementation between the clods if they exist, thus causing the formation of a fragile soil body. On the other hand, clay is responsible for the formation of stable soil clods or secondary aggregates. The presence

of a substantial proportion of lime within the clod apparently weakens the cementing strength of the clay and causes the clod to break down readily under the forces of weathering and cultivation.

The data obtained in this study substantiate these conclusions. (Table 4). Thus, as shown in Figure 15, the mechanical stability of clods from the high-lime soils was considerably lower than the mechanical stability of clods of the low-lime soils of similar texture. Furthermore, the percentage of erodible fraction in the high-lime soils was substantially higher than the percentage of erodible fraction in the low-lime soils of similar texture and depth (Figure 13). The erodibility of the high-lime soils was likewise substantially higher in comparable cases (Figure 11). Figure 10 also shows a lower degree of cloddiness in the high-lime than the low-lime soils, especially at a comparable depth near the surface. In one case (sandy loam) the marked difference in texture between the high- and the low-lime soil at a depth below the surface masked whatever difference might have been due to lime (Figure 10).

<u>The influence of water-stable structure on soil cloddiness.</u>--The size-distribution of soil particles and aggregates in water was determined to check its influence on soil cloddiness and erodibility.

A perusal of the data in Table 3 will show that most of the soils analysed contain a small proportion of water-stable particles or aggregates of a size not erodible by wind, that is, greater than 0.84 mm. in diameter. In 23 of 24 cases analyzed, the amount of the water-stable grains greater than 0.84 mm. in the surface soil did not exceed 2.6 percent. The amount of semi-erodible grains (0.42 to 0.84) was greater, but in no case did it exceed 12.8 percent. In the great majority of cases the amount was much smaller. At lower depths the amount of semi- and non-erodible water-stable fractions was somewhat greater. Evidently, these water-stable grains broke down somewhat when exposed to the forces of the weather near the surface. A 12.8 percent content of semi-erodible grains in the surface soil was found on Site 18. Virtually all these grains were coarse sand that moved readily in the wind tunnel. The soil was one of the three most erodible of those tested. On this farm, the 12.8 percent of the semi-erodible water-stable grains and the 0.6 percent of the non-erodible ones apparently failed to reduce the erodibility appreciably. A markedly lower erodibility of other soils containing even less of the semi- and non-erodible water-stable grains was apparently due to other factors responsible for soil cloddiness. These dryland soils evidently lack sufficient amounts of coarse water-stable grains or aggregates to resist the wind. The resistance of these soils to wind action evidently depends primarily on their ability to form massive secondary aggregates considerably larger than the largest water-stable grains.

The formation of secondary aggregates of a size too large to be moved by wind is a function of the amount of silt and clay particles (smaller than 0.02 mm.) dispersible in water. Figure 16 shows an inverse association between the percentage of particles less than 0.02 mm. dispersed in water and the percentage of dry fractions erodible by wind. Loam and clay loam had the highest proportion of water-dispersible particles smaller than 0.02 mm. in diameter and, therefore, the lowest proportion

of fractions erodible by wind. Loamy sand, on the other hand, had the lowest proportion of the fine water-dispersible particles and, therefore, the highest proportion of erodible fraction. The water-dispersible particles of the size of silt and clay were apparently responsible for the formation of secondary aggregates, or clods resistant to wind erosion. These fine particles are perhaps of organic as well as mineral origin. Certainly the largest of these would be mainly quartz silt but the finer and hence the more active cementing particles may be the mucilaginous materials of decomposing organic matter as well as the particles of clay.

The influence of deep plowing.--Two fields, Sites 23 and 24, plowed to a depth of 16 to 20 inches in the spring of 1952 were sampled to the depth of plowing and analyzed in the usual manner. The soil as obtained from the field was virtually non-erodible when exposed to wind in the tunnel (Table 3). The degree of cloddiness and the mechanical stability of the clods was comparable to that obtained from deeper layers of similar texture from unplowed fields. A shallow mantle of drifting sand was buried by the plowing and soil considerably higher in clay was brought up from below. The massive clods brought to the surface will no doubt disintegrate to finer fractions in a relatively short time. The real significance of the plowing, however, is the bringing up of a more clayey soil material to the surface. A more clayey soil will no doubt maintain a more cloddy and less erodible structure as long as no soil drifting occurs. If soil drifting through some future negligence or climatic mishap should recur, clay would be sorted out and removed and the field would once again be covered with drifting sand. If this occurs, the condition will be much more serious because the mantle of sand will be deeper and no more clayey material will be available to bring to the surface, unless plowing is deeper than 16 or 20 inches. Such a condition apparently has occurred on Site 16 of the Stanford farm. The soil there apparently was deep plowed in the past. Now it contains about an equal proportion of sand (over 85 percent) all the way down to 16 inches in depth (Table 3). Any plowing attempted in the future to reduce erosion by wind will have to be considerably deeper than 16 inches. It will be of substantial benefit only if more clayey material can be found below this depth. Otherwise, deep plowing will have only a temporary beneficial effect. Usually a maximum disintegration of clods is reached within a year after they are brought to the surface by plowing. After this initial period, the degree of cloddiness depends primarily on the proportion of clay in the surface soil.

Other Soil Properties of Field Areas

While complete data were not obtained on all fields, the pH, total soluble salts, organic matter content, percent of $CaCO_3$, and the dispersion ratio of soil samples from 12 field sites were determined. These analyses were carried out in the soils laboratory of the Soil Conservation Service Regional Office at Albuquerque, New Mexico. They are summarized in Table 4.

The pH level of all the soils to 6-inch depth was uniformaly high and the measured differences appear to be minor.

The finer textured soils have more soluble salts and a higher organic matter level than the coarser soils. Associated with the conditions of wind erosion present, is the tendency for soluble salts to be removed from the immediate surface. The organic matter content ranges from 0.6 to 1.0 percent in the soils of 3 texture and from 0.1 to 0.3 percent in the soils of 5 texture.

Discussion and Conclusions

Various procedures of study have tended to bring out the influence of many factors associated with the wind erosion phenomena in Roosevelt and Curry Counties, New Mexico.

The portable wind tunnel, used in the field, gages the combined effects of surface conditions present at the time of study. Many of these conditions are transitory. Much of the variability is creditable to surface roughness, plant residue, and the size of the soil particles exposed at the immediate surface. Reasonable estimates of erodibility can be made using these factors. Use of a surface wind drag of 3,000 pounds per acre as an interpretive basis of comparison is somewhat arbitrary but approaches a value associated with the gusts of atmospheric wind. Again, the condition provided by the tunnel is one of soil removal. In the field, problems are associated not only with the condition of removal but also with mass transfer from place to place, and accumulation.

Conditions of study of soil samples in the small trays differ considerably from those in the field. The average force applied to the soil in the trays was about 1/10 of that used in field tests. The effects of roughness and residue are of necessity largely eliminated. The quantity of soil eroded appears to be in the neighborhood of 1/20 the loss that would be obtained for similar surface conditions with the field tunnel, although there is no way known of relating one to the other with certainty due to the many variables involved. Use of small trays eliminates many of the field variables and provides a controlled condition well adapted for studying the erodible nature of the soil.

The climatic factors associated with the wind erosion problem are extremely important. The combination of drought and winds apparently was not so severe in the spring of 1952 as during the mid-thirties. Based on the interpretation of the records from the N. W. Portales location, conditions approaching those of 1952 would be expected about 25 percent of the time. More serious trouble would be expected should the present drought continue into another year.

The fields sampled appear adequate to approximate typical conditions of surface roughness and residues present on the soils of varying texture and structure. The rating of surface and cover conditions brings out the fact that the poorest protection exists on the soils of coarsest texture and vice versa. At the same time, the coarser soils are basically the most erodible.

There are several properties of plant residue besides its kind and weight. Its orientation on the surface is partially evaluated by the "equivalent roughness" values obtained by use of the tunnel. Density and height of the residue are important. Where sorghum stubble is about one foot high it appears to be effective provided it has sufficient density to cause the wind to flow over the stubble rather than through it. The amount of leaves present on the stubble appears to have considerable effectiveness. The use of varieties tending to produce and retain leaves near the ground should be encouraged.

Delaying wheat stubble land fallowing operations until after spring winds are past appears to be one of the best methods of soil protection from spring winds. Fortunately the delayed fallow is feasible during drought periods when little or no fall weed growth occurs.

Where clods brought up by the chisel are too isolated and massive, emergency controls are not too effective. The wind may flow around them and be concentrated on the erodible portion of the soil. This condition was present on Site 11. Better protection would be obtained with an equal weight of clods of somewhat smaller size.

Other factors being equal, erodibility of a soil by wind is dependent primarily on the proportion of erodible fractions present at its surface in a dry state. Few soil particles moved by wind exceed 0.84 mm. in diameter. The relative erodibility of cultivated soils can be estimated by dry sieving procedure. All that is essential is a 0.42 or a 0.84 mm. sieve and a chart indicating the relative erodibility as governed by the amount of erodible fraction less than 0.42 or less than 0.84 mm. in diameter. It is essential that the dryness of the soil and vigor of sieving be uniform in all comparable tests. A mechanical control of the vigor and time of sieving is desirable.

There are several important secondary factors influencing clod structure and erodibility of soil by wind. These are, (1) soil texture, (2) degree of compaction with depth, (3) the size distribution of particles and grains in water, and (4) free calcium carbonate, or lime.

Clay is the most active textural soil fraction having a marked influence on soil cloddiness. The greater the amount of clay up to a certain proportion the greater is the cloddiness and the lower the erodibility. This proportion of clay has been found previously to be about 27 percent. None of the soils studied had sufficient clay near the surface to produce a maximum degree of cloddiness.

Clay was found to increase with depth in all soils studied. This variation with depth has an important significance with respect to the use of listing and deep plowing for wind erosion control.

The increase of clay with depth is due to two principal factors--the geologic processes of weathering and illuviation and the sorting action of the wind. Within the cultivated zone much clay and some silt

at the surface were removed by recent winds, leaving the sand behind. This sorting action of the wind when continued for many years causes the soils to become progressively coarser in texture and more erodible. Deep plowing to bring clay to the surface is immediately beneficial in reducing the rate of erosion, but must be supplemented with effective methods of wind erosion control if a steady deterioration in soil texture and irreparable increases in erodibility are to be avoided.

In addition to the effects of higher clay content, the increased cloddiness at lower depths is due to greater compaction. Clods at lower depths have a higher degree of mechanical stability than clods near the surface because of this greater compaction. A more mechanically stable clod is less subject to breakdown by cultivation and by abrasion from drifting soil. In consequence, tillage implements of the chisel type, designed to bring clods from below are valuable in controlling erosion by wind. The process of compaction is going on continually below the surface of the ground; hence tillage methods that utilize this process for wind erosion control are of definite value.

Cloddiness and erodibility also are influenced by the size-distribution of water-stable particles and aggregates after dispersion in water. Since the water-stable particles represent the more stable particles to which the soil may be disintegrated in the field, it may be expected that an increase in their size will increase the resistance of the soil to wind erosion. A great majority of the water-stable aggregates in all the soils studied were too small to resist the wind. The resistance of these soils to wind erosion is dependent primarily on their ability to form secondary aggregates, or clods.

Cloddiness appears to be due in large measure to the amount of water-dispersible particles of the size of silt and clay (less than 0.02 mm.). These particles are soil cements composed of a variety of materials: some are particles of quartz silt, some are clay particles, and others are organic colloidal particles. Dispersed fine silt, although usually not considered as soil cement, acts as a weak cement after the soil is wetted and dried. Silt disperses readily in water. The presence of large amounts of dispersed silt particles in a soil forms a cloddy, massive structure which, while resistant to wind erosion, may present a serious structure problem especially in humid and sub-humid regions. The water-dispersible particles of the size of clay possess a considerably stronger cementing power and are perhaps mainly responsible for the formation of mechanically stable clods.

In the presence of substantial amounts of calcium carbonate, such as exist in high-lime soils, the dispersed particles of the size of clay tend to flocculate and lose part of their cementing power. Thus, clods impregnated with calcium carbonate become fragile and disintegrate readily under the influence of cultivation and abrasion. The lime crystals act as a weak cement much like particles of silt. Thus, some coarse textured soils containing little quartz silt or clay but impregnated with substantial amounts of lime tend to become cemented and

to produce clods more readily than similar textured soils that contain little or no lime. Such clods are weak, however, and break up readily under cultivation and impacts of drifting sand.

A considerable scatter of individual values about the average may be observed in most of the figures presented. This scatter is due in part to errors of the experiment, but more particularly to many unaccountable factors. One of these is the variable depth of surface soil and depth of sampling. Another is the variation in the past history of the individual fields, together with differences in cropping and tillage methods, all of which cause marked differences in soil structure and erodibility.

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Table 1. -- Data pertaining to secondary sites selected for semi-portable wind tunnel studies.

Site No.	Farm	Location	Soil Unit	Erosion	Soil Type	Stubble	Tillage
20	Lavender	Sec. 15, T6N, R31E	4331	Moderate wind	Dalhart sandy loam	None	Listed
21	Fahsholtz (2)	Sec. 6, T4N, R37E	3331	Moderate wind	Dalhart loam	Wheat	One-way
22	Fahsholtz (3)	Sec. 6, T4N, R37E	3331	Moderate wind	Dalhart loam	Wheat	One-way
23	Pember	Sec. 19, T1S, R35E	5331	Moderate wind	Dalhart loamy sand	None	Deep-plow
24	Fleming	Sec. 23, T3S, R34E	4331	Moderate wind	Dalhart sandy loam	None	Deep-plow

Table 2.--Surface condition and cover ratings of fields and ratings required to reduce erosion losses to given minimum.

Site	Soil unit	Estimated soil loss[1]	Measured soil loss	Index Estimated loss / Measured loss	Surface condition and cover rating		
					Existing	Required for <1 Ton/A. loss	Required for <5 Tons/A. loss
No.		Tons/A.	Tons/A.				
1	3221	75	0.062	1210	Excellent	Good	Good
2	3221	65	40.5	2	Poor	Good	Good
3	3331	66	1.1	60	Fair	Good	Good
4	3331	21	.3	70	Fair	Good	Fair
5	33L3k	200	41.5	5	Poor	Excellent	Good
6	4331	450	21.4	21	Fair	Excellent	Good
7	4331	84	9.8	9	Poor	Good	Good
8	4331	92	2.6	35	Fair	Good	Good
9	4331	31	2.2	14	Fair	Good	Fair
10	4331	240	24.4	10	Poor	Excellent	Good
11	4331	65	21.4	3	Poor	Good	Good
12	43L3k	480	21.9	22	Fair	Excellent	Good
13	43L3k	175	21.2	8	Poor	Excellent	Good
14	43L2k	240	1.5	160	Good	Excellent	Good
15	43L2k	330	5.8	57	Fair	Excellent	Good
16	5331	390	7.7	51	Fair	Excellent	Good
17	5331	910	230.0	4	Poor	Excellent	Excellent
18	5331	390	89.8	4	Poor	Excellent	Good
19	5331	900	125.5	7	Poor	Excellent	Excellent

[1] Losses estimated for a soil surface having a roughness equivalent of K = 2 inches and a weight of residue, R = 100 Lbs./Acre. (From the straight line plotted in figure 6).

Site no.	Soil type and unit	Depth	Mechanical composition			Dry aggregate distribution							Mechanical stability of clods	Amount eroded 1/	Water-stable particle distribution				
			Sand	Silt	Clay														
			> 0.05 mm.	.05-.002 mm.	< 0.002 mm.	> 38 mm.	38-12.7 mm.	12.7-6.4 mm.	6.4-2.0 mm.	2.0-.84 mm.	.84-.42 mm.	< 0.42 mm.			> 0.84 mm.	.84-.42 mm.	.42-.05 mm.	.05-.02 mm.	< 0.02 mm.
		Inches	%	%	%	%	%	%	%	%	%	%	%	T./A.	%	%	%	%	%
1	Pullman loam, 3221	0- 1	43.9	37.4	18.7	0	2.6	6.2	7.4	6.4	7.8	69.6	59	2.0	0.6	3.4	52.4	36.0	7.6
		1- 5	42.9	38.9	18.2	0	9.4	11.0	10.8	9.0	8.8	51.0	72	0.3	1.8	7.2	54.6	27.0	9.4
		5-14	34.5	31.1	34.4	17.4	38.0	10.6	14.3	10.5	4.6	4.6	96	0	14.1	13.1	42.4	20.0	10.4
2	Pullman loam, 3221	0- 1	68.5	14.8	16.7	0	1.7	5.0	6.5	7.3	11.1	68.4	76	1.6	1.6	8.1	63.1	20.4	6.8
		1- 4	47.2	31.1	21.7	0	10.5	12.9	14.0	9.9	9.2	43.5	80	0.1	2.8	7.0	57.8	22.0	10.4
		4-12	39.4	29.7	30.9	12.2	29.1	15.8	18.0	10.1	4.8	10.0	95	0	15.8	10.0	47.4	16.4	10.4
3	Dalhart loam, shallow phase, 3331	0- 1	48.2	38.7	13.1	0	4.0	5.2	7.8	6.4	7.8	68.8	87	0.6	1.7	4.4	72.7	14.0	7.2
		0- 8	49.6	32.7	17.7	30.8	16.4	6.4	8.2	5.4	4.5	28.3	91	0.2	3.0	4.1	74.1	12.4	6.4
4	Portales loam, 3331	0- 1	52.9	31.2	15.9	0	14.2	10.1	7.7	4.4	4.5	59.1	64	0.6	0.8	1.8	76.2	14.0	7.2
		1- 5	53.8	32.5	13.7	23.4	18.2	9.9	7.0	3.2	3.7	34.6	82	0	0.8	2.0	78.8	12.4	6.0
		5-15	44.4	33.4	22.2	29.8	29.0	9.3	6.4	3.6	4.3	17.6	87	0	5.2	4.0	66.8	14.4	9.6
5	Church loam, 33L3k	0- 1	73.8	14.7	11.5	0	3.2	3.5	4.5	3.3	5.5	80.0	71	6.2	2.6	4.0	73.0	16.0	4.4
		0- 5	44.1	41.3	14.6	3.4	6.7	7.0	7.4	4.8	4.8	65.9	75	0.6	3.0	3.3	61.7	24.0	[illegible]
		12-18	28.9	15.5	55.6	12.5	20.2	15.8	23.6	11.5	5.2	11.2	99.9	0	27.8	14.7	35.9	5.6	16.0
6	Dalhart fine sandy loam, shallow phase 4331	0- 1	80.6	9.2	10.2	0	0.9	1.8	2.0	1.8	4.3	89.2	67	15.9	1.7	3.6	84.3	8.0	2.4
		0- 8	74.0	8.8	17.2	21.2	18.4	8.1	6.7	3.7	3.8	38.1	91	0.1	1.7	4.2	77.3	10.0	6.8
		0-16	70.9	10.4	18.7	26.2	22.0	8.9	7.9	4.6	3.8	26.6	92	0.06	4.7	4.5	74.0	10.0	6.8
7	Dalhart fine sandy loam, shallow phase 4331	0- 1	75.1	11.2	13.7	0	6.4	8.6	6.6	3.4	4.8	70.2	77	2.7	0.4	3.7	80.1	13.0	2.8
		0- 8	72.5	9.8	17.7	12.8	27.5	9.8	7.4	3.6	3.8	35.1	93	0.1	1.7	4.2	79.3	9.0	5.8
8	Dalhart fine sandy loam, 4331	0- 1	77.7	9.0	13.3	0	8.8	5.7	6.5	3.6	4.0	71.4	75	6.3	0.5	1.9	79.6	14.0	4.0
		0- 8	76.9	9.0	14.1	5.7	19.7	7.2	8.0	3.8	2.8	52.8	86	0.5	2.0	2.1	75.1	16.4	4.4
		0-16	73.0	8.9	18.1	18.7	30.6	9.6	8.4	4.2	3.1	25.3	92	0.2	5.8	3.5	72.7	12.0	6.0
9	Dalhart fine sandy loam, 4331	0- 1	76.2	10.3	13.5	0	14.0	8.3	7.6	4.2	4.2	61.8	74	1.8	0.7	1.7	92.4	0.8	4.4
		0- 8	71.5	14.0	14.5	0	19.9	10.0	8.4	4.8	4.2	52.6	78	0.7	0.7	2.7	80.2	10.0	6.4
10	Dalhart loamy fine sand or sandy loam 4331	0- 1	82.6	7.1	10.3	0	3.4	5.4	4.4	2.7	2.1	82.0	51	8.0	0.5	1.8	93.3	4.0	0.4
		1- 8	78.9	8.8	12.3	0	15.2	13.0	9.1	3.9	2.6	56.2	64	0.5	0.3	1.2	89.1	9.0	0.4
		8-15	69.0	9.2	21.8	25.5	32.7	9.3	8.6	4.3	2.8	16.8	94	0	3.4	4.0	76.8	11.0	4.8
11	Dalhart fine sandy loam, 4331	0- 1	83.3	4.4	12.3	0	18.1	6.6	4.2	1.4	1.3	68.4	75	3.0	0.4	1.6	89.6	7.6	0.8
		1-12	72.1	11.6	16.3	11.6	13.7	9.2	6.3	2.5	3.1	53.6	75	0.2	0.2	2.6	90.8	4.0	2.4
		12-20	61.5	13.6	24.9	23.7	28.5	12.4	12.7	7.0	4.8	10.9	97	0	14.6	3.9	65.1	10.0	6.4
12	Arch loamy sand or sandy loam, 43L3k	0- 1	83.6	7.2	9.2	0	2.0	1.8	2.2	1.6	2.3	90.1	57	29.8	0.8	3.1	89.1	5.8	1.2
		1- 5	61.2	24.3	14.5	0	15.2	8.8	9.8	7.1	6.3	52.8	70	0.4	5.4	6.5	62.9	16.0	9.2
		5-15	51.1	21.3	27.6	22.9	19.3	9.5	9.1	7.0	6.4	25.8	83	0.06	11.9	9.3	52.4	19.0	7.4
13	Arch loamy sand or sandy loam, 43L3k	0- 1	81.7	5.2	13.1	0	3.6	4.7	5.0	3.6	5.1	78.0	58	5.0	6.2	4.3	82.1	5.8	1.6
		1- 5	75.5	14.3	10.2	2.0	21.8	10.4	9.3	5.7	6.9	43.9	76	0.1	7.9	8.3	75.4	5.8	2.6
		5-15	64.3	8.2	27.5	8.7	35.9	10.6	8.9	5.5	6.2	24.2	85	0	9.7	8.3	70.8	6.4	4.8
14	Arch loamy sand 43L2k	0- 1	79.5	10.1	10.4	0	1.9	4.8	4.4	3.2	4.6	81.1	54	2.5	1.0	3.4	82.8	10.0	2.8
		1- 5	79.4	5.9	14.7	23.4	18.2	9.9	7.0	3.2	3.7	34.6	76	0.1	0.5	3.5	81.8	10.0	4.2
		5-15	74.8	6.0	19.2	29.8	29.0	9.3	6.4	3.6	4.2	17.7	87	0	0.7	4.5	80.6	10.6	4.2
15	Portales sandy loam 43L2k	0- 1	82.0	9.0	9.0	0	3.8	2.8	3.1	2.3	3.0	85.0	59	11.1	1.0	2.7	87.9	6.0	2.4
		1- 5	76.0	10.1	13.9	0	22.7	12.3	9.9	5.0	3.9	46.2	76	0.02	0.6	2.2	86.2	7.0	4.0
		5-15	62.4	15.2	22.4	25.6	29.8	10.3	8.8	5.1	4.2	16.2	90	0	6.3	6.1	68.0	13.0	6.6
16	Dalhart loamy fine sand, 5331	0- 1	86.1	3.4	10.5	0	2.4	3.2	2.8	1.6	2.7	87.3	39	14.6	0.6	2.2	91.2	4.0	2.0
		0- 8	85.5	3.8	10.7	4.0	13.9	5.8	3.8	1.4	1.8	69.4	58	1.5	0.4	2.0	91.0	5.0	1.6
		0-16	87.1	3.2	9.7	12.8	16.6	6.2	3.6	1.2	1.2	58.4	72	0.6	0.1	1.7	91.0	4.0	1.6
17	Dalhart loamy fine sand, 5331	0- 1	89.9	1.2	8.9	0	0.4	0.6	0.4	0.2	1.0	97.5	38	76.0	0.3	2.2	95.1	2.0	0.4
		0- 8	89.1	1.4	9.5	0	1.0	1.8	2.0	1.8	4.3	89.1	52	3.3	0.4	2.0	91.2	5.0	1.4
		0-20	85.6	2.6	11.8	2.5	14.8	8.0	6.2	3.2	3.8	61.5	84	0.5	0.6	1.9	91.1	4.0	2.4
18	Amarillo loamy sand 5331	0- 1	86.2	4.4	9.4	0	0.2	0.4	0.2	0.4	11.2	87.6	30	39.2	0.6	12.8	83.8	2.0	0.8
		0-16	81.4	3.5	15.1	19.1	12.2	6.2	5.5	2.8	6.6	47.6	81	0.3	2.0	6.6	84.6	5.0	1.8
19	Amarillo loamy sand 5331	0- 1	84.5	4.4	11.1	0	0.2	0.4	0.4	0.5	1.3	97.2	57	41.1	0.3	1.6	85.1	10.0	3.0
		0-16	80.8	2.5	16.7	17.8	18.0	7.6	6.0	2.8	5.0	42.8	84	0.1	0.4	4.6	82.2	9.0	3.8
20	Dalhart sandy loam 4331	0- 1	75.7	12.6	11.7	0	17.2	13.3	7.6	3.8	4.1	54.0	77	1.6	1.6	4.4	74.4	14.0	5.6
		1- 4	70.5	15.3	14.2	0	23.9	12.3	7.7	3.6	4.2	48.3	73	0.4	0.5	3.6	74.7	14.4	6.8
		4- 8	59.4	15.1	25.5	34.2	37.8	9.1	8.1	3.8	2.2	4.8	97	0	0.8	6.0	64.4	18.4	10.4
21	Dalhart loam, 3331	0- 1	64.7	18.1	17.2	0	8.2	4.8	10.5	6.1	5.8	64.6	85	0.4	0.7	2.3	69.0	22.4	5.6
		1- 5	43.5	39.4	17.1	28.5	19.5	11.0	9.0	4.7	3.7	23.6	88	0	0.9	2.2	68.5	18.0	10.4
		5-15	33.8	40.0	26.2	40.3	35.7	9.6	6.8	2.7	1.4	3.5	96	0	1.0	3.8	58.0	25.4	11.8
22	Dalhart loam, 3331	0- 1	70.8	14.5	14.7	0	1.6	4.3	4.8	3.3	4.4	81.6	84	2.5	1.0	2.4	76.2	13.4	7.0
		1- 5	44.0	39.1	16.9	16.8	28.1	14.0	10.8	5.4	3.6	21.3	88	0.1	1.5	2.8	70.5	16.0	9.2
		5-15	36.7	37.9	25.4	25.4	43.1	10.3	8.6	4.2	2.4	6.0	97	0	2.3	3.4	63.9	22.0	8.4
23	Dalhart loamy sand 5331	0-16	81.4	6.2	12.4	8.6	21.2	9.4	6.4	3.1	8.1	43.2	77	0.04	2.0	4.6	79.0	8.8	5.6
24	Dalhart sandy loam 4331	0-16	70.6	7.9	21.5	42.4	11.8	8.1	8.0	5.0	4.4	20.3	95	0.01	0.5	9.0	80.3	3.0	7.2

Note: See table 1 for description of site numbers 20 to 24, inclusive.

1/ Amounts eroded were obtained from tray samples.

Table 3.--Properties and erodibility of soils at various depths.

Table 4.--pH, total soluble salts, organic matter, $CaCO_3$ content, and dispersion ratio determinations for selected sample sites.

Site No.	Farm	Depth	pH		Total soluble salts	Organic matter	$CaCO_3$ (lime)	Dispersion
			Paste	1:5				
		Ins.			%	%	%	%
2	Fahsholtz	0-1	7.7	8.2	0.07	1.0	T	10.5
		1-4	7.7	8.1	.11	1.0	0.3	10.8
3	Gammill	0-1	6.7	7.2	.08	.9	0	10.0
		1-6	6.6	7.0	.10	.8	0	8.9
4	Orphanage	0-1	8.1	8.5	.08	.6	1.0	45.3
		1-5	7.9	8.9	.13	.6	.9	18.9
8	Viazant	0-1	7.4	8.0	.10	.5	0	10.0
		1-6	7.5	8.0	.12	.4	0	8.2
12	Stephenson	0-1	7.8	8.5	.02	.8	7.4	17.9
		1-6	7.7	8.2	.05	1.0	15.4	30.9
13	Wivel	0-2	7.8	8.6	.02	.6	6.5	21.4
		2-6	7.9	8.7	.02	.7	8.8	32.1
14	Near	0-1	7.7	8.4	.02	.7	.4	13.8
		1-5	7.8	8.5	.02	.6	6.5	21.4
15	Freeman	0-1	7.9	8.7	.10	.5	4.6	12.6
		1-5	8.0	8.7	.05	.6	3.9	10.7
16	Stanford	0-1	7.4	7.8	.02	.2	0	18.8
		1-6	7.3	7.7	.02	.2	.1	11.0
17	Widner	0-1	7.6	8.5	.02	.3	0	24.0
		1-8	7.6	8.3	.02	.3	T	14.3
18	Moore	0-1	7.3	7.8	.02	.3	0	12.9
		1-6	7.1	7.7	.02	.3	T	8.0
19	Betts	0-1	7.2	7.7	.02	.1	0	8.8
		1-6	6.9	7.5	.02	.3	0	11.7

Analyses performed by M. L. Seal at the SCS-College cooperative laboratory located at the New Mexico A. & M. College, State College, New Mexico.

Sites omitted in the sequence were not sampled.

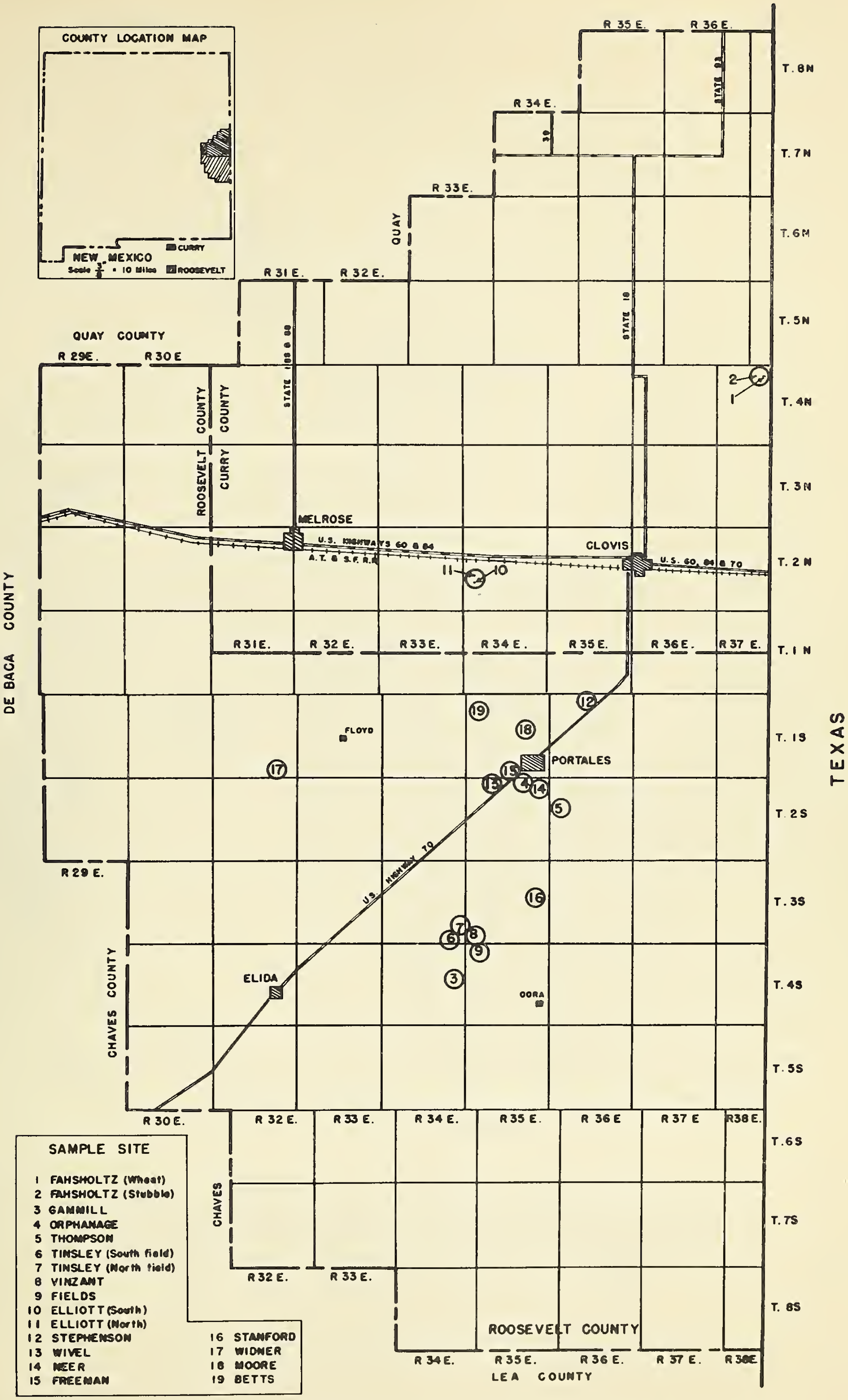

Figure 1.--Map of Roosevelt and Curry Counties, New Mexico showing location of primary sites selected for study.

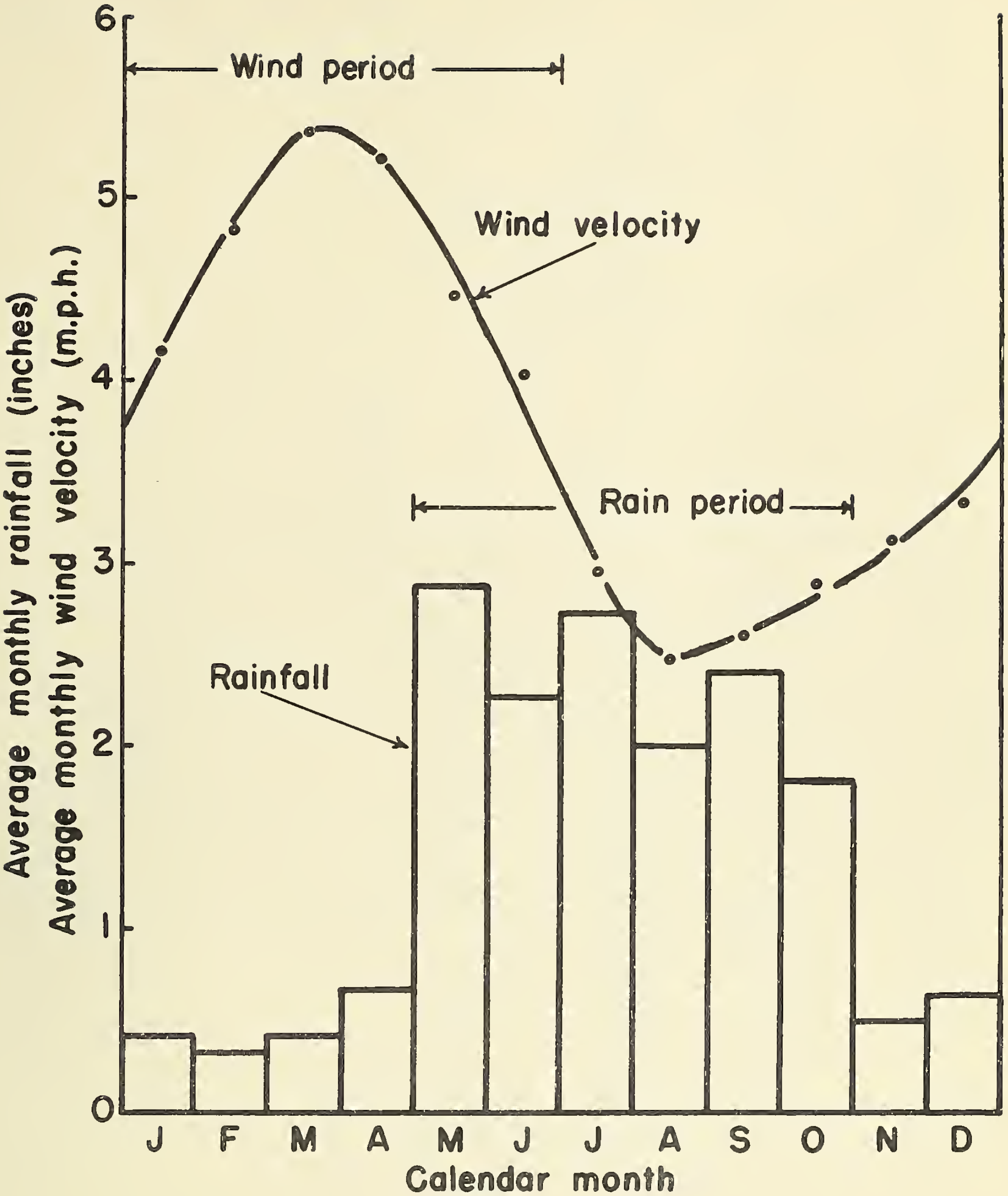

Figure 2.--Average distribution of rainfall and wind movement by calendar months, 1935-1952. Data are for station seven miles northwest of Portales, New Mexico.

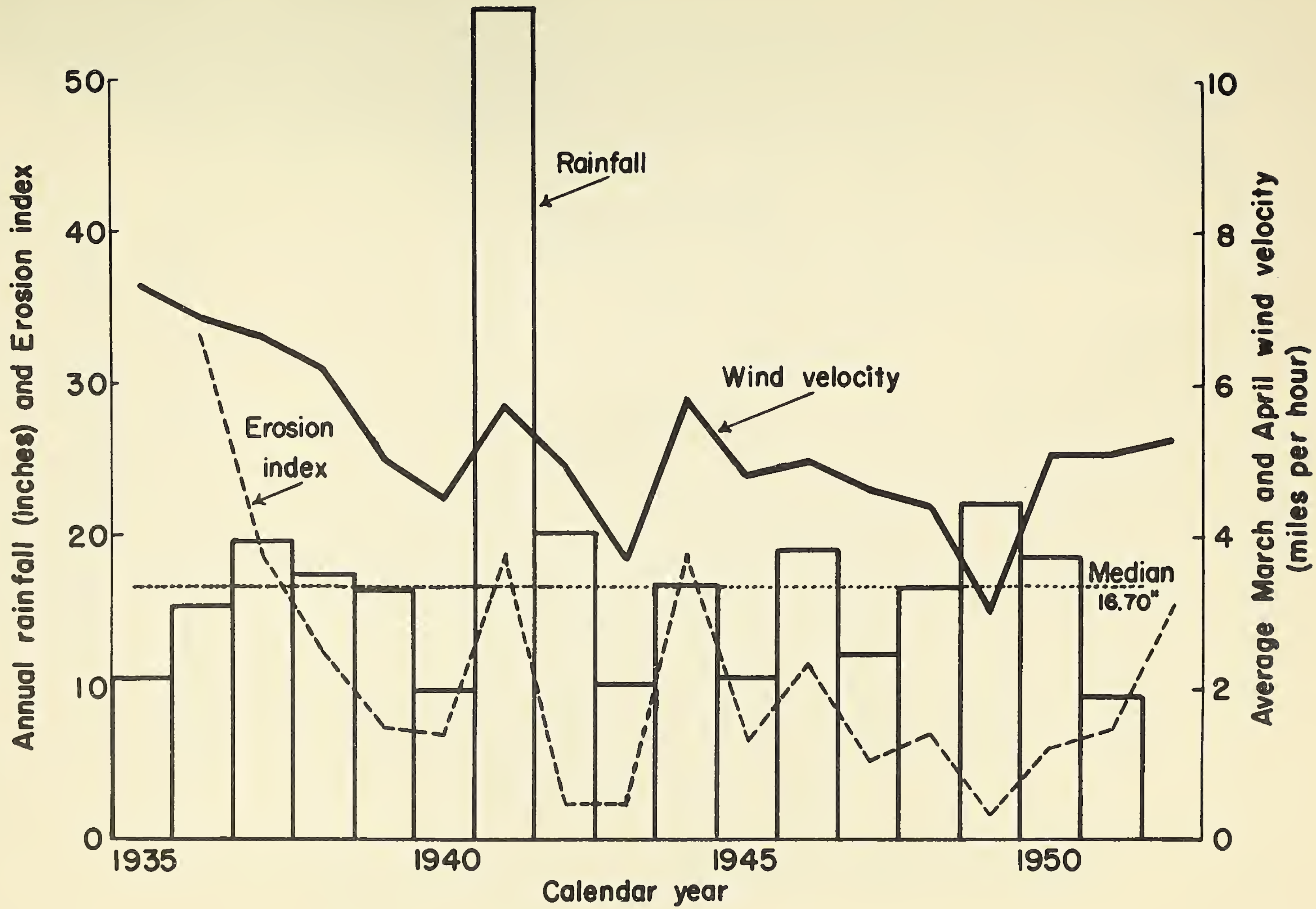

Figure 3.--Rainfall, wind velocity, and erosion index, 1935-1952. Data are for station seven miles northwest of Portales, New Mexico.

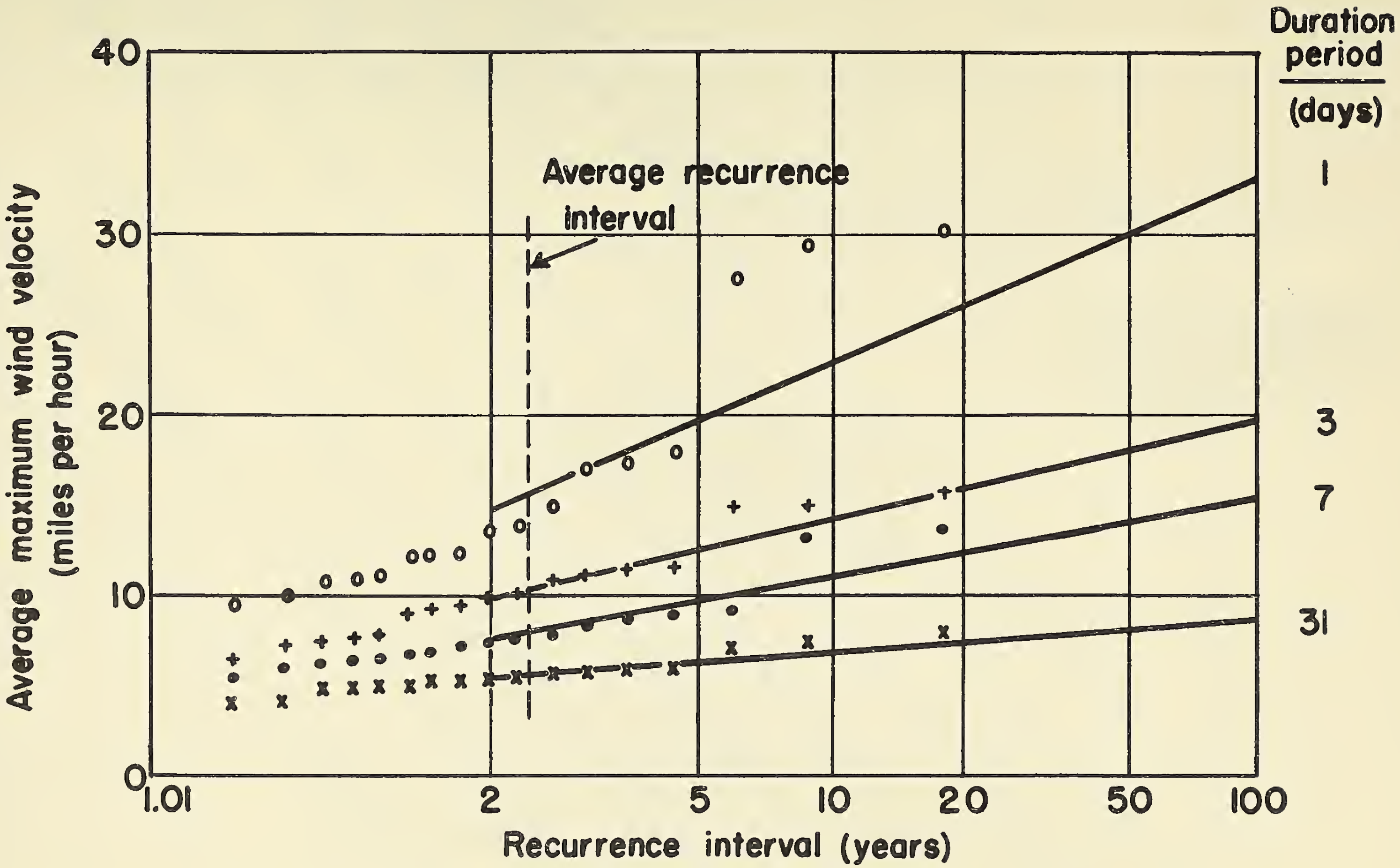

Figure 4.--Intensity-frequency data for wind movement during month of March from 1935-1952. Data from 2-foot gage at station seven miles northwest of Portales, New Mexico.

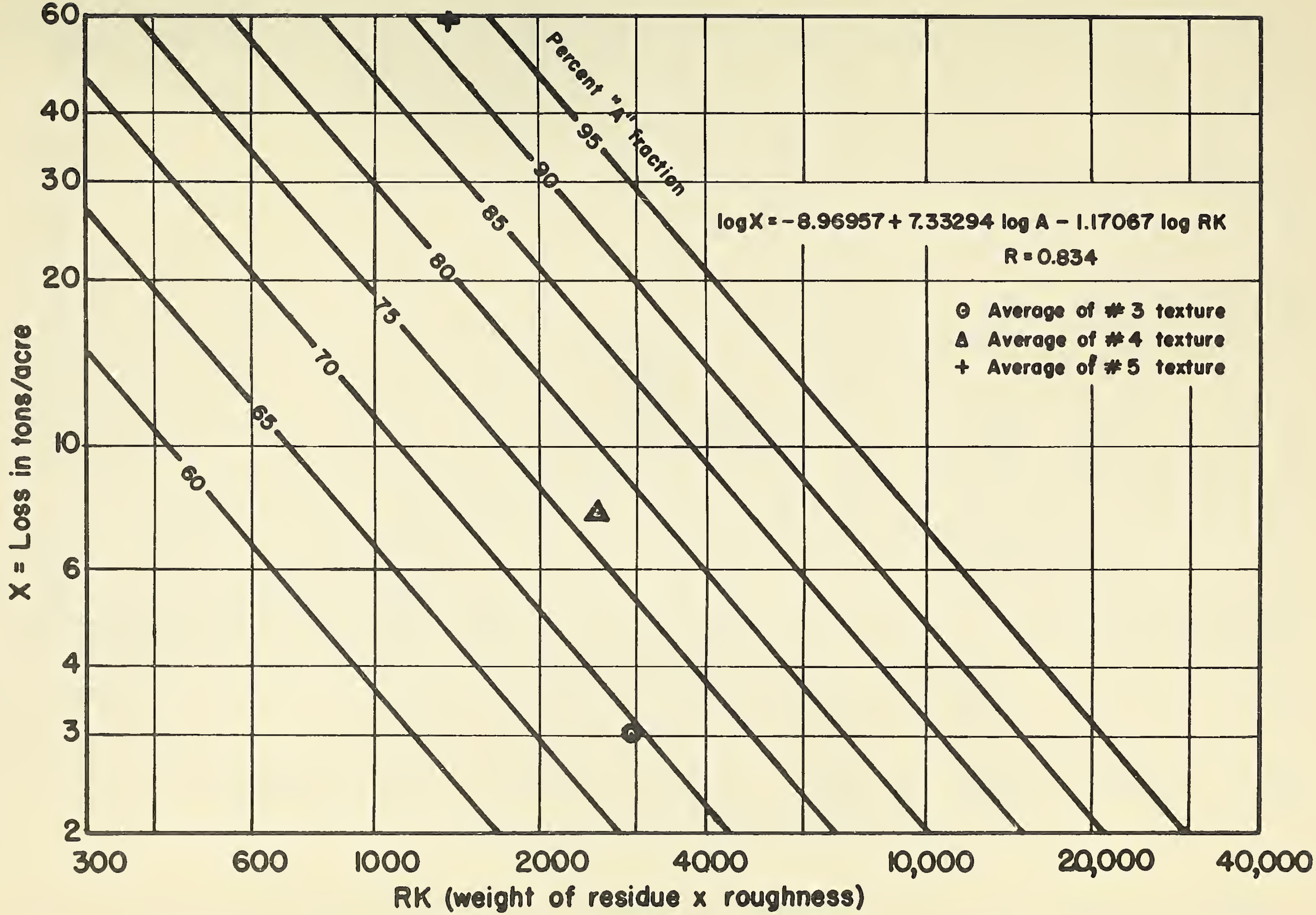

Figure 5.--Graphical solution of soil loss from tunnel for varying values of RK and percent of A fraction.

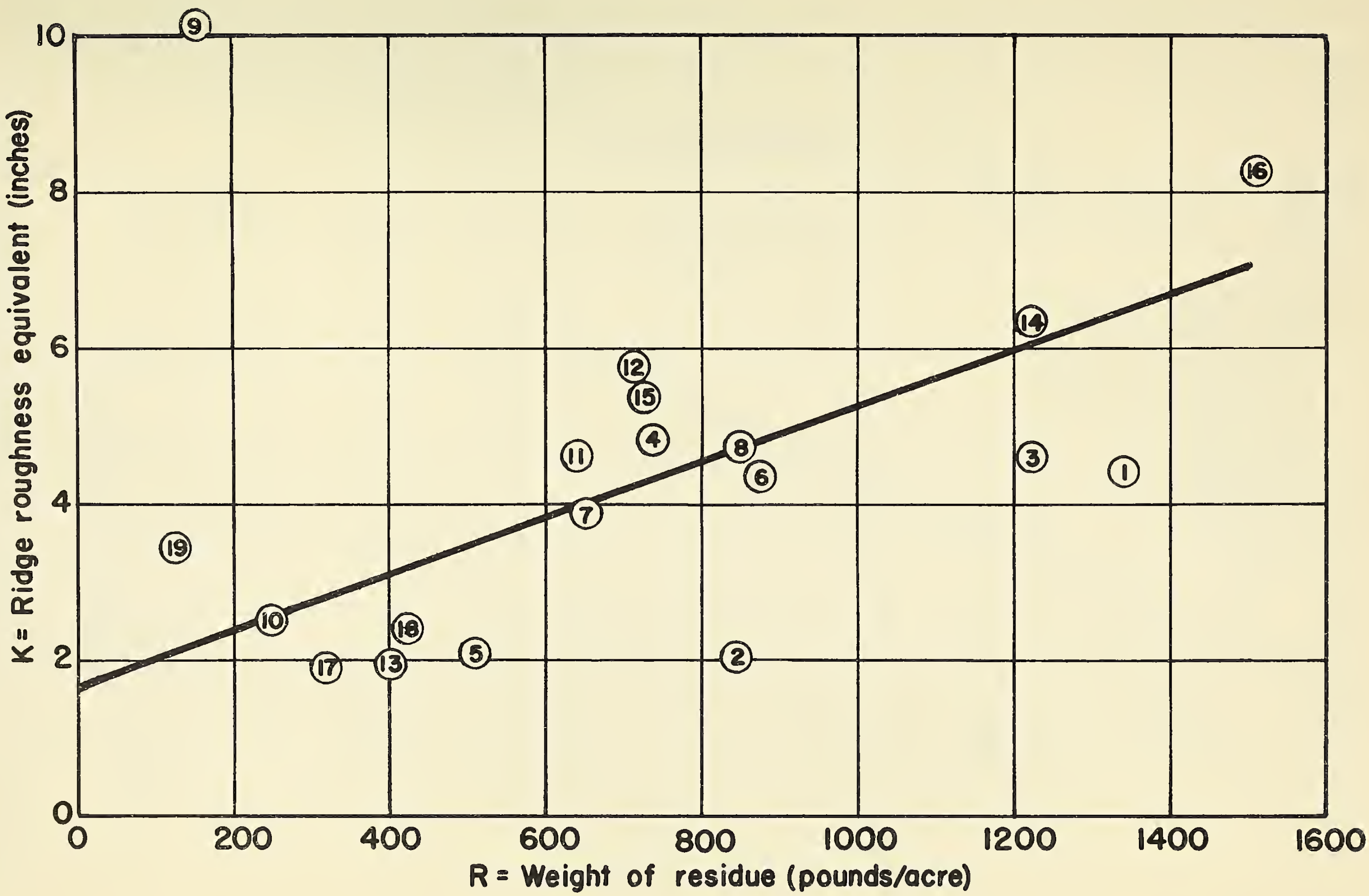

Figure 6.--Relationship of K, the ridge roughness equivalent, to R, the weight of surface residue, on primary study sites.

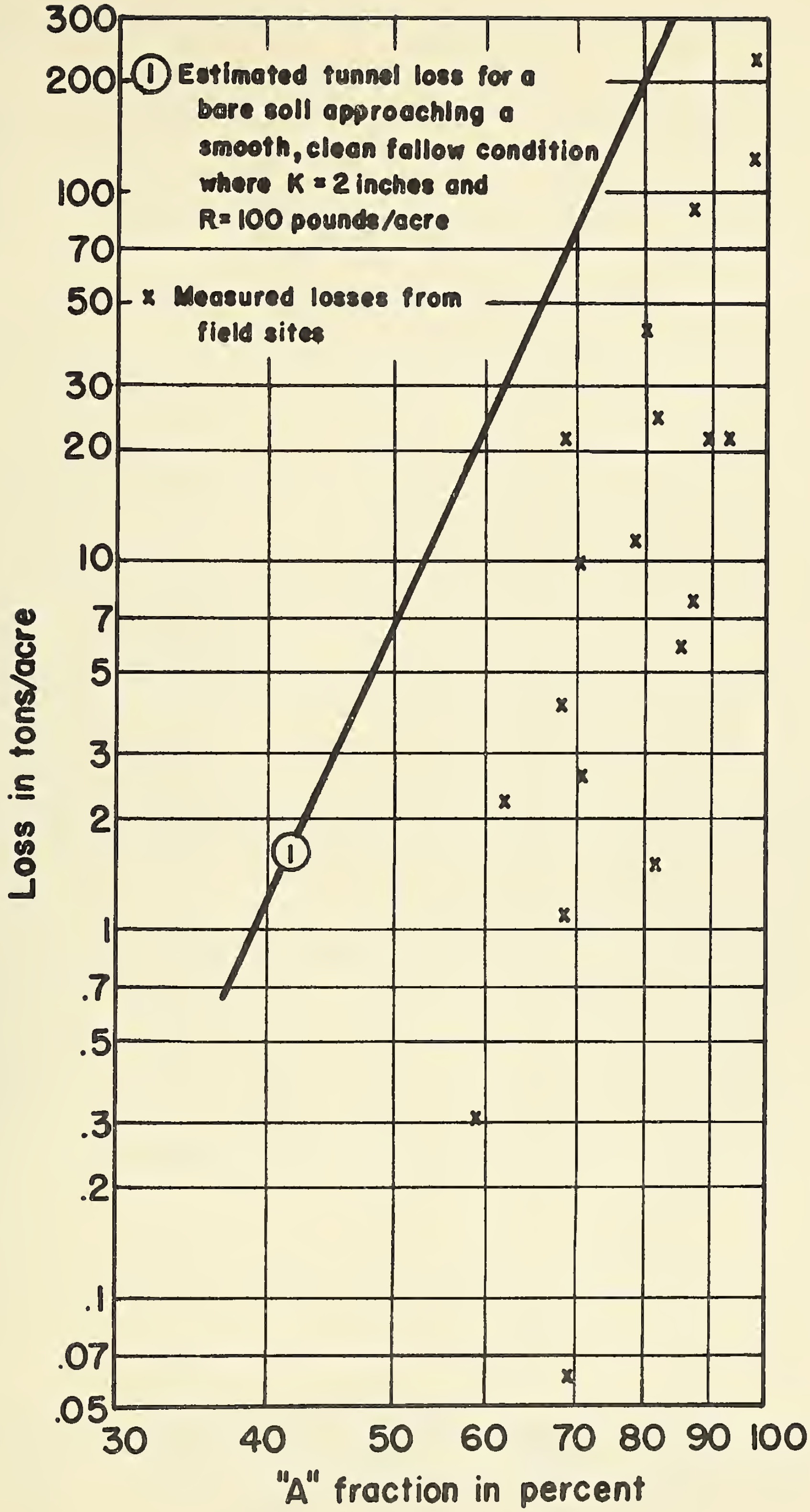

Figure 7.--Tunnel losses estimated for a bare soil condition, and measured losses in relation to A, the percent of surface soil fractions of size < 0.42 mm. in diameter.

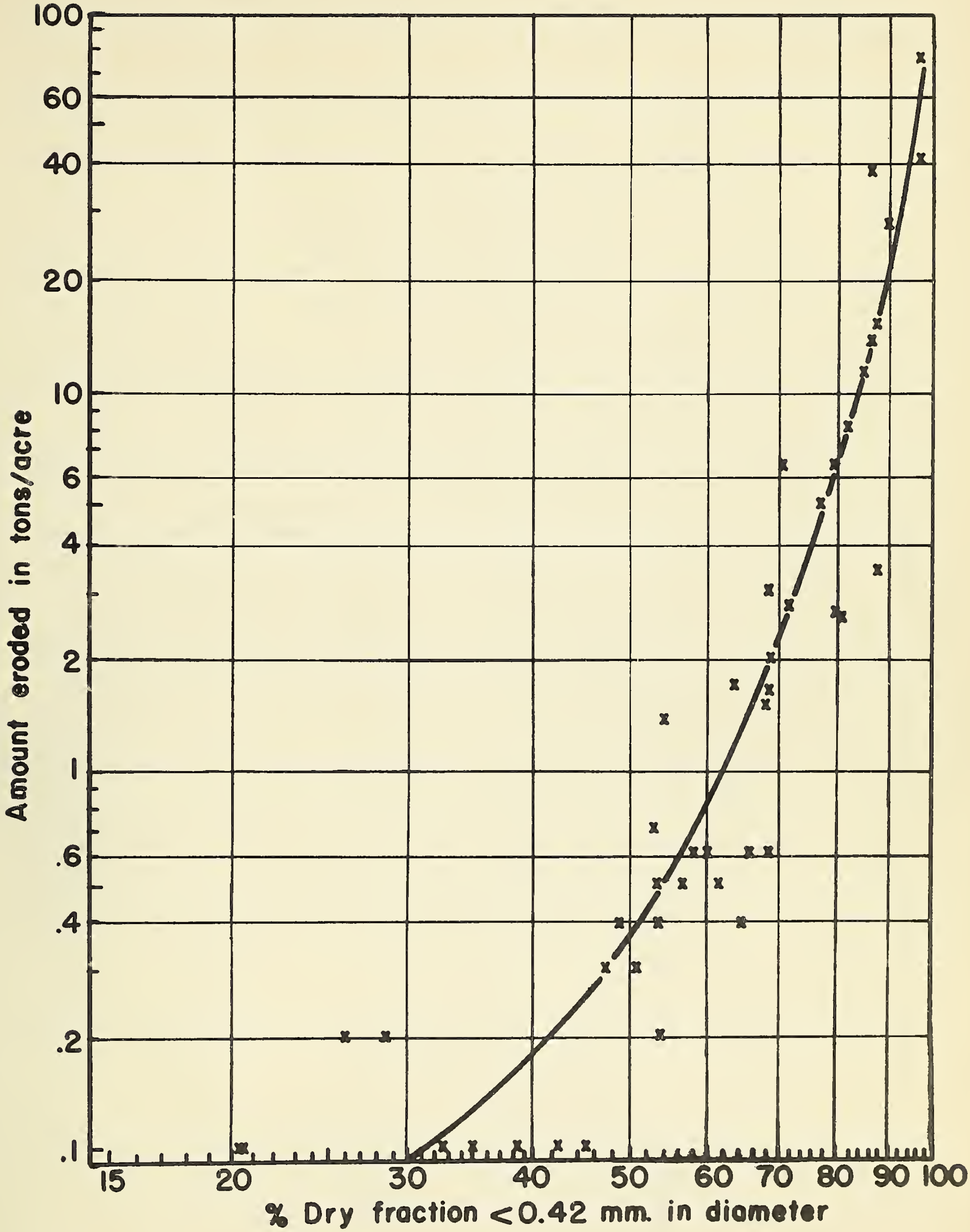

Figure 8.--Relation of soil erodibility to the proportion of dry soil fractions < 0.42 mm. in diameter.

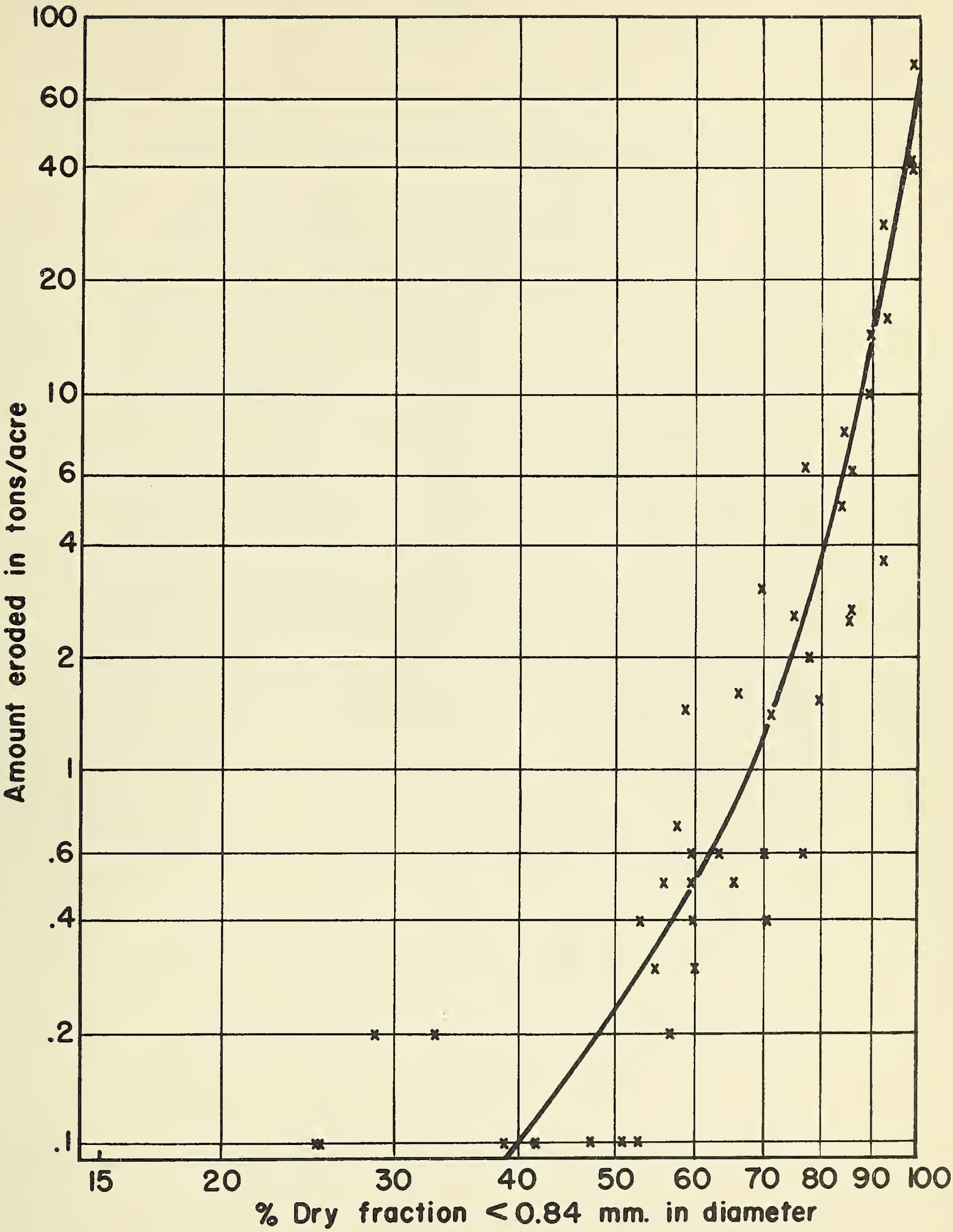

Figure 9.--Relation of soil erodibility to the proportion of dry soil fractions < 0.84 mm. in diameter.

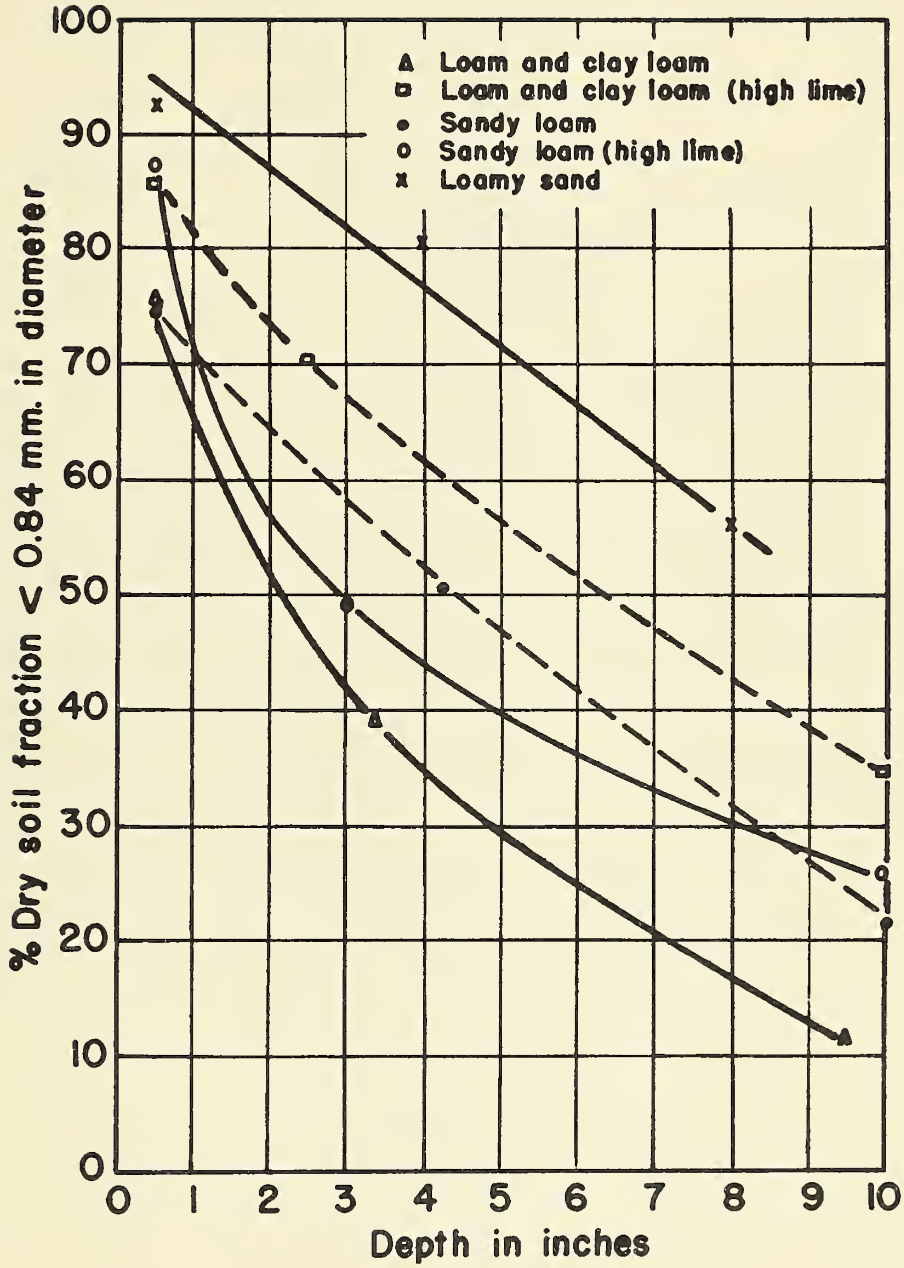

Figure 10.--Amounts of erodible soil fraction of various soil classes at different depths.

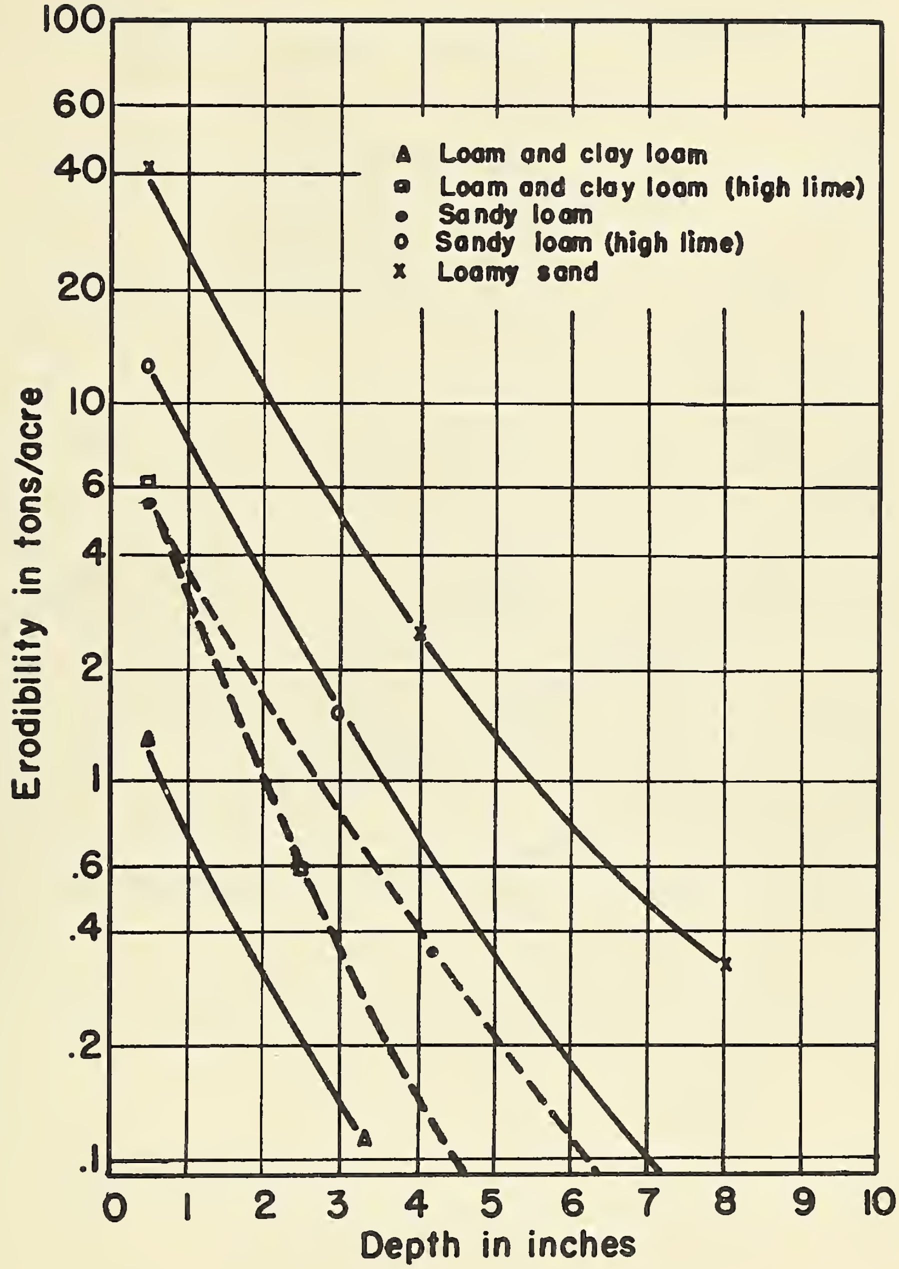

Figure 11.--Erodibility of various soil classes at different depths.

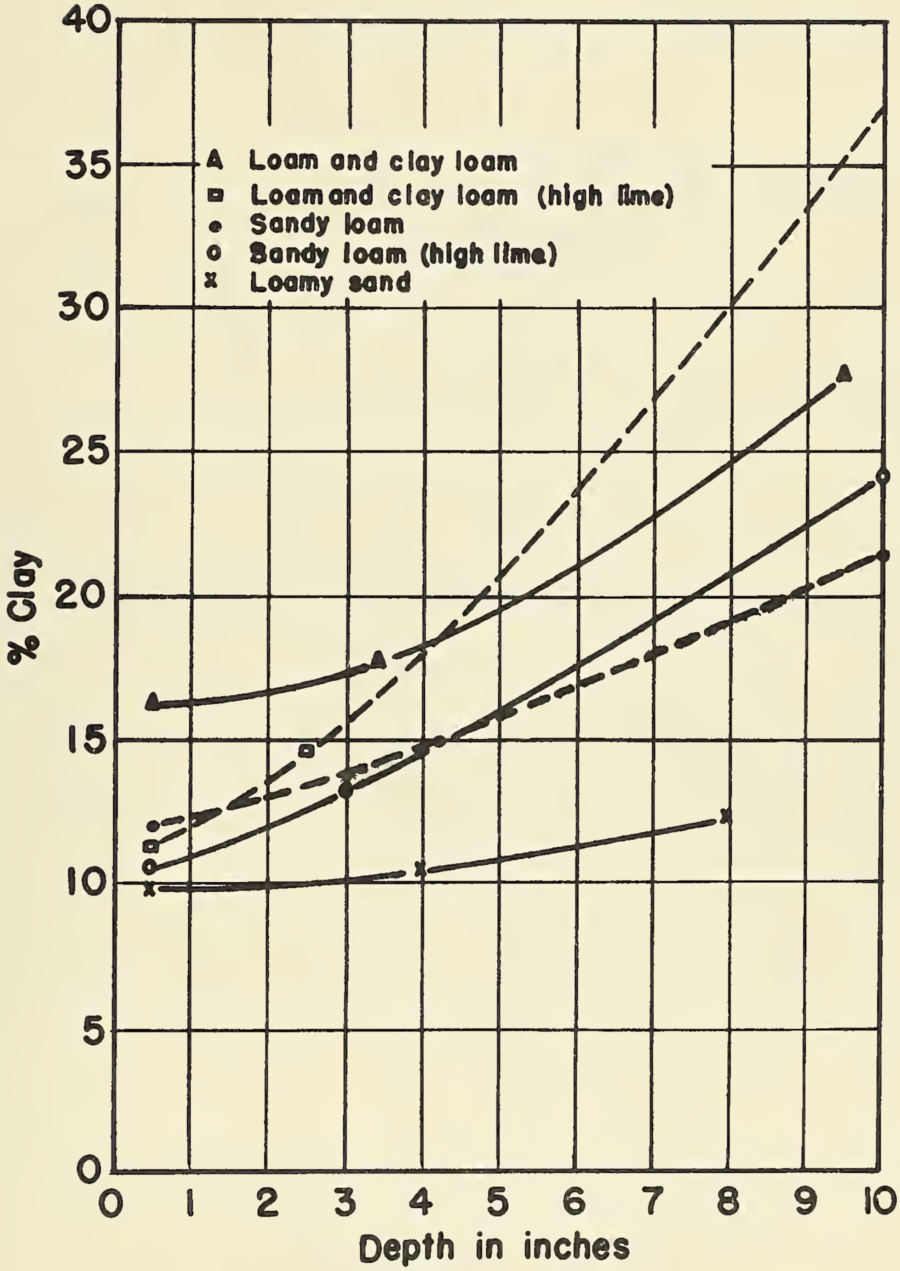

Figure 12.--Percentage of clay in various soils at different depths.

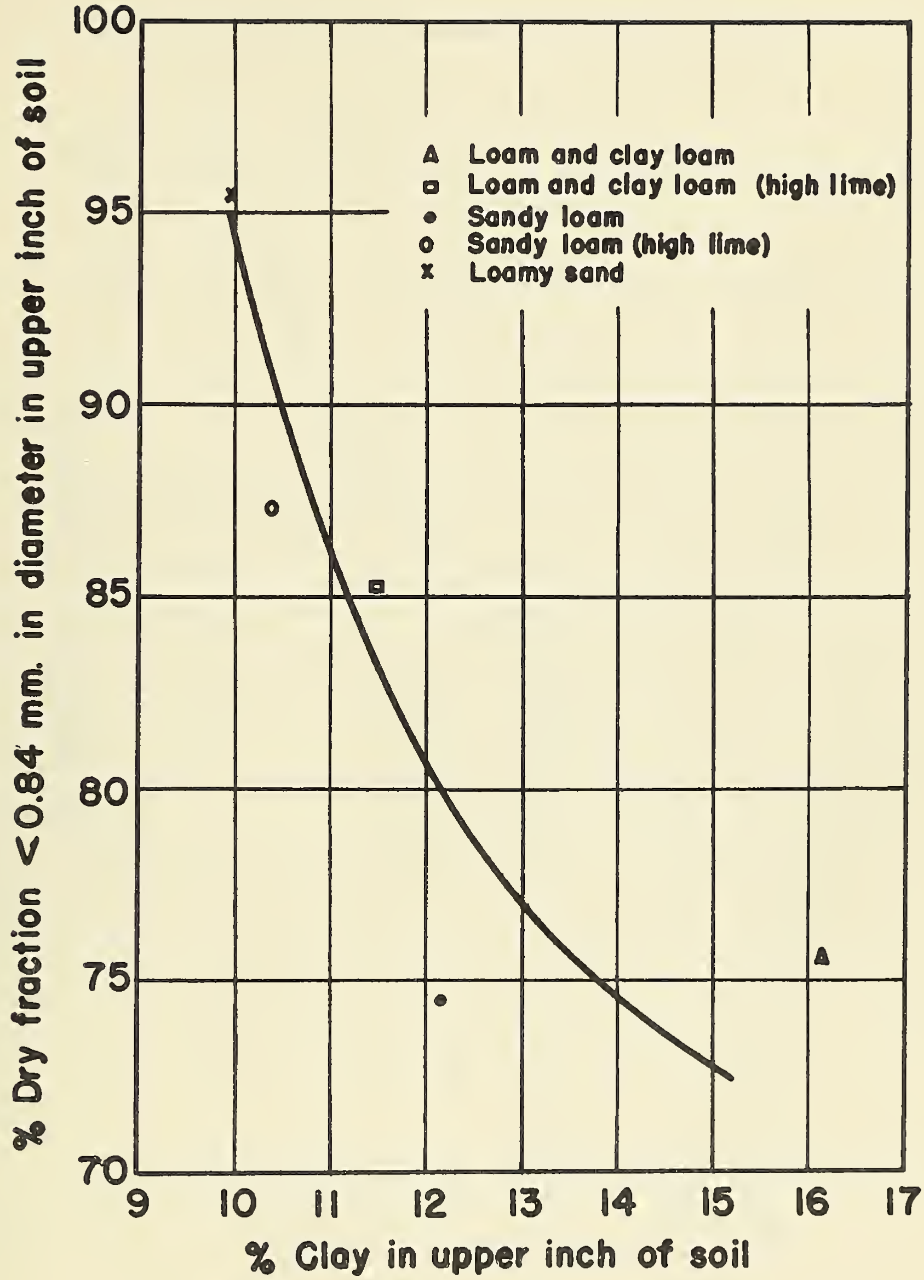

Figure 13.--Relation of erodible soil fraction to the percentage of clay in upper inch of soil.

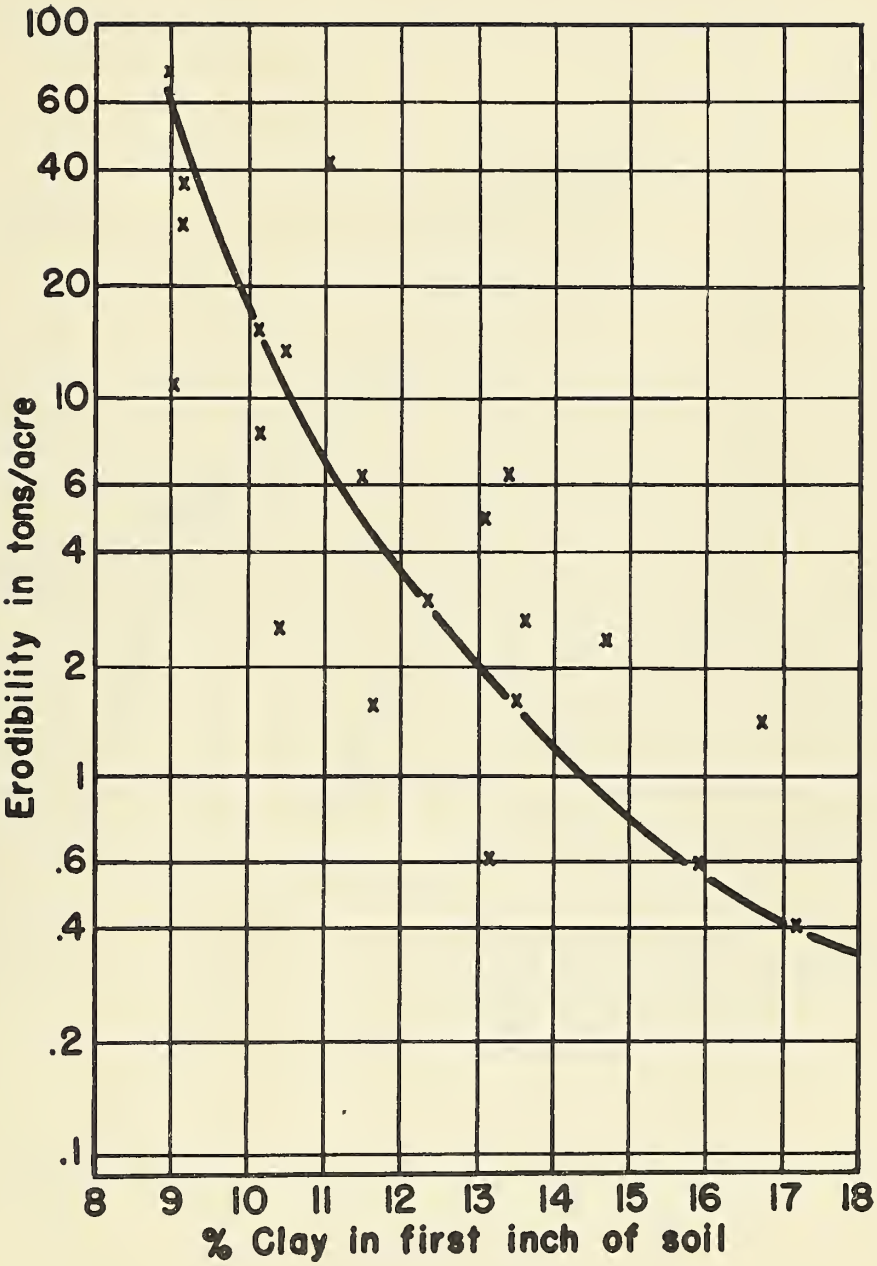

Figure 14.--Relation between erodibility and the percentage of clay.

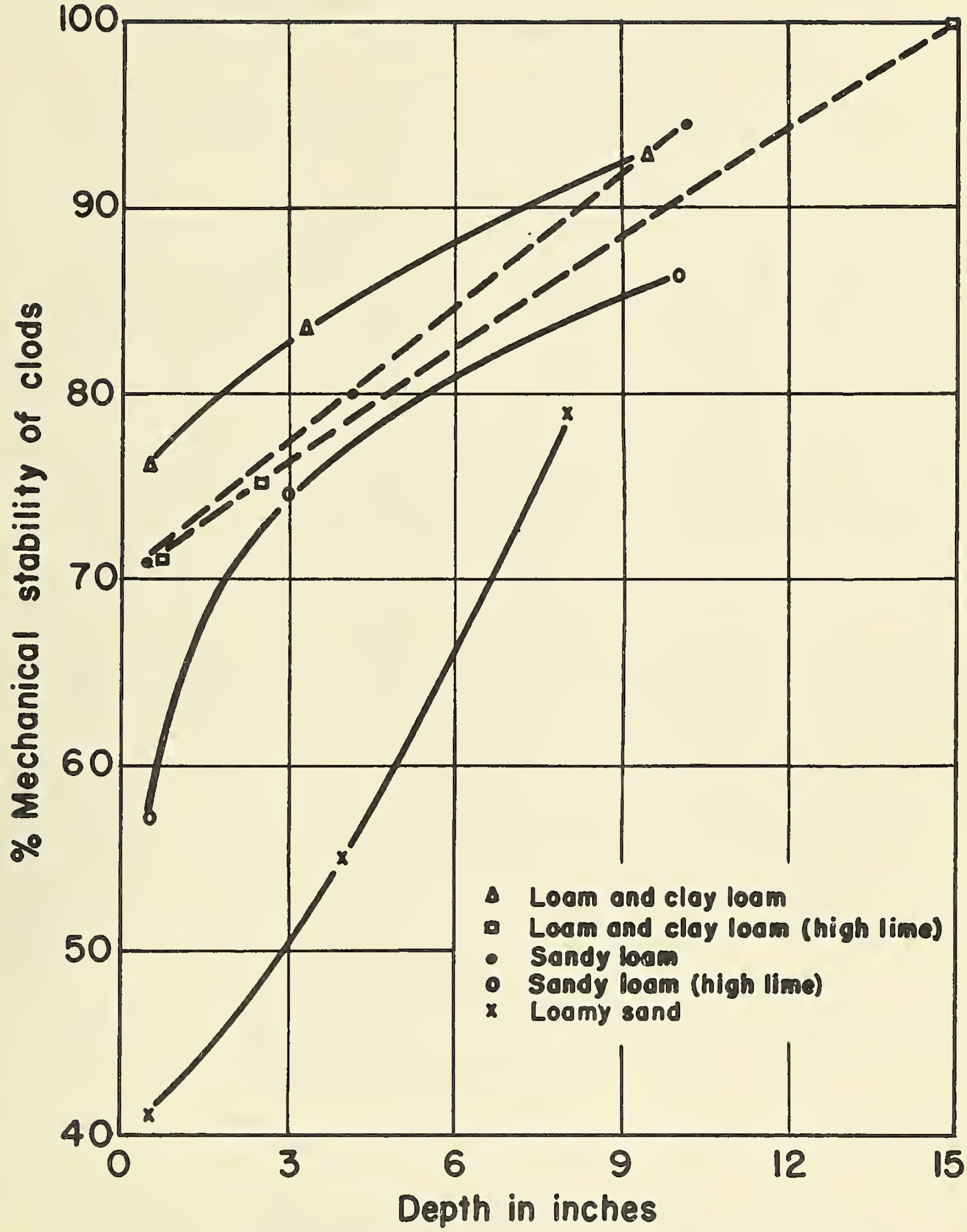

Figure 15.--Mechanical stability of clods of various soil classes at different depths.

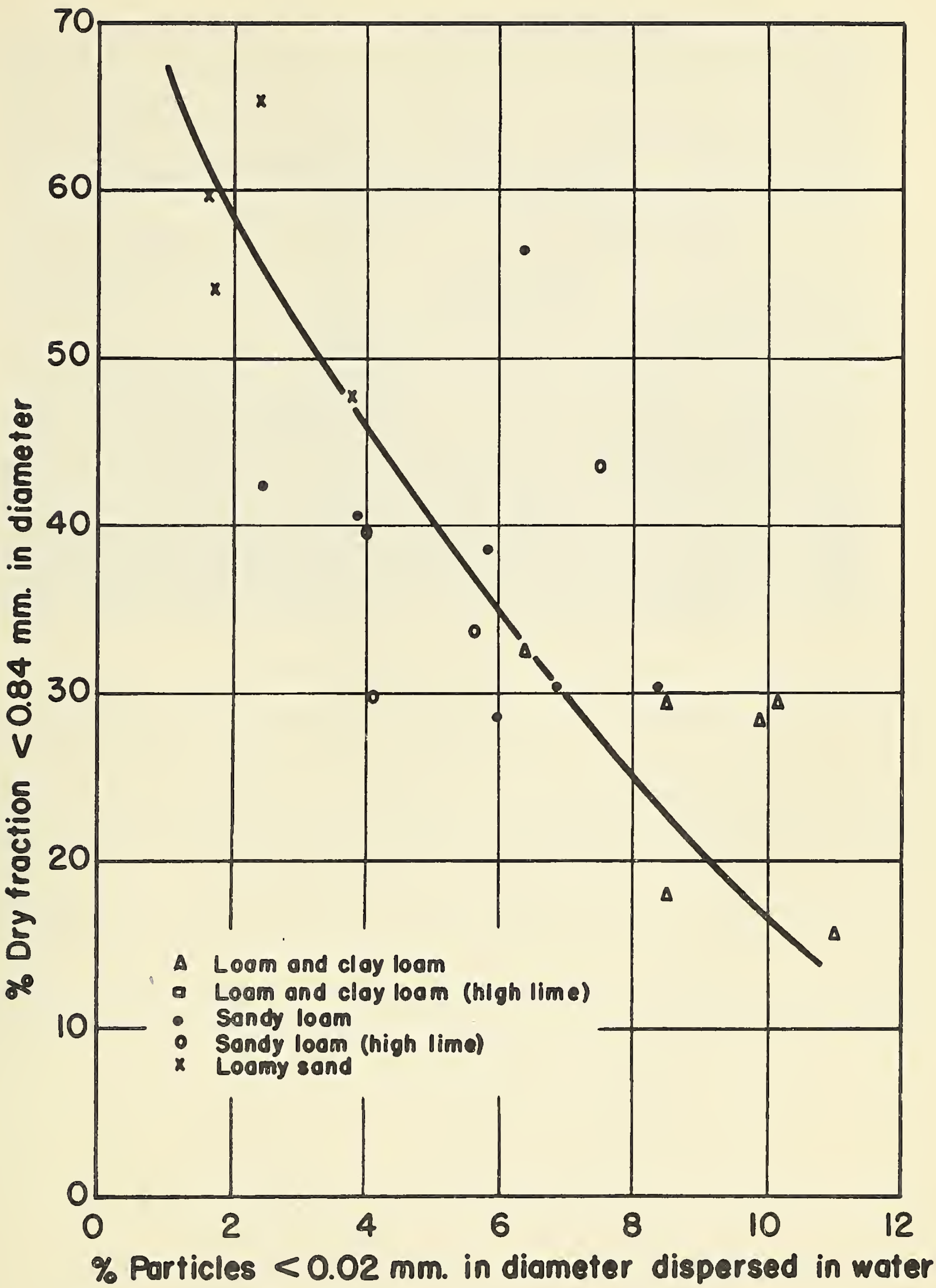

Figure 16.--Relation between amount of erodible soil fraction and the percentage of particles < 0.02 mm. dispersed in water. (Based on values down to depth of cultivation.)

WIND EROSION FIELD EQUIPMENT

Portable equipment used in making field studies is carried on two one-half ton pickups and a 2-ton truck.

The lead pickup truck contains a motor-generator, dust collection and sampling equipment used in conjunction with the portable wind tunnel.

The 2-ton truck transports the primary units of the portable wind tunnel.

The last one-half ton pickup contains soil structure analysis equipment, soil sampling trays, scales, and residue sampling devices.

SITE 1

FAHSHOLTZ FARM (Sec. 3 - T4N - R37E), Curry County, New Mexico

April 14, 1952. Wheat stubble from 1951 crop left undisturbed under a delayed fallow system. Moisture has been insufficient for the emergence of weed growth. Excellent protection is afforded by the stubble which is approximately 7 inches in height.

Soil Unit: 3221   Soil Type: Pullman loam   Erosion: P

Soil Surface:
Mechanical composition - - - - 43.9% sand; 37.4% silt; 18.7% clay
Residue: wheat stubble- - - -1340 lbs. per acre
Ridge roughness equivalent - - 4.40 inches
Soil material < 0.42 mm. - - - 69.6%
Soil eroded by tunnel- - - - - 0.062 tons per acre

Surface and Cover Condition:
Excellent

SITE 2

FAHSHOLTZ FARM (Sec. 3 - T4N - R37E), Curry County, New Mexico

April 14, 1952. Sorghum stubble from 1951 crop. Field has been cultivated and stubble is broken down and scattered unevenly over the soil surface. Natural wind has eroded soil from spot areas where the residue cover is inadequate.

Soil Unit: 3221 Soil Type: Pullman loam Erosion: P

Soil Surface:
- Mechanical composition - - - - 68.5% sand; 14.8% silt; 16.7% clay
- Residue: sorghum stubble- - - 845 lbs. per acre
- Ridge roughness equivalent - - 2.05 inches
- Soil material < 0.42 mm. - - - 68.4%
- Soil eroded by tunnel- - - - - 40.5 tons per acre

Surface and Cover Condition:
Poor

SITE 3

GAMMILL FARM (Sec. 13 - T4S - R33E), Roosevelt County, New Mexico

April 10, 1952. Native sod broken in 1950 and field drilled to sorghum in 1951. The growth of sorghum has been unsatisfactory. The soil surface is well protected by sod or grass residue which has not decomposed under prevailing dry conditions.

Soil Unit: 3331   Soil Type: Dalhart loam   Erosion: P

Soil Surface:
  Mechanical composition - - - - 48.2% sand; 38.7% silt; 13.1% clay
  Residue: sorghum stubble- - - 400 lbs. per acre
           sod remnants - - - - 820 lbs. per acre
           total- - - - - - - - -1220 lbs. per acre
  Ridge roughness equivalent - - 4.58 inches
  Soil material < 0.42 mm. - - - 68.9%
  Soil eroded by tunnel- - - - - 1.10 tons per acre

Surface and Cover Condition:
  Fair

SITE 4

ORPHANAGE FARM (Sec. 2 - T 2S - R34E), Roosevelt County, New Mexico

April 16, 1952. Residue of 1951 sudan grass crop. Harvested for seed at a height of 9-12 inches. The stubble is quite dense, averaging about 370,000 stalks per acre. In addition, a considerable number of weeds (sunflower) have grown up in the row making it more effective as a protective covering to the soil. This field is farmed under an irrigation system.

Soil Unit: 3331 Soil Type: Portales loam Erosion: P

Soil Surface:
Mechanical composition - - - - 52.9% sand; 31.2% silt; 15.9% clay
Residue: sudan grass stubble
and weeds- - - - - 735 lbs. per acre
Ridge roughness equivalent - - 4.8 inches
Soil material < 0.42 mm. - - - 59.2%
Soil eroded by tunnel- - - - - 0.3 tons per acre

Surface and Cover Condition:
Fair

SITE 5

THOMPSON FARM (Sec. 18 - T2S - R35E), Roosevelt County, New Mexico

April 10, 1952. Relatively unproductive high lime area. Considerable removal of soil by wind has occurred and the field has been shallow-listed to control blowing with little success. Residues have been partially destroyed and those present are affording poor protection to the surface. This is the fourth crop of sorghum after breaking the field from native sod.

Soil Unit: 33L3k Soil Type: Church loam Erosion: R

Soil Surface:
- Mechanical composition - - - - 73.8% sand; 14.7% silt; 11.5% clay
- Residue: sorghum stubble- - - 505 lbs. per acre
- Ridge roughness equivalent - - 2.10 inches
- Soil material <0.42 mm. - - - 80.0%
- Soil eroded by tunnel- - - --- 41.5 tons per acre

Surface and Cover Condition:
Poor

SITE 6

TINSLEY FARM (South field) Sec. 36 - T3S - R33E), Roosevelt County, New Mexico.

April 9, 1952. Sorghum harvested to leave stubble 10-12 inches high. The stubble is above average in density with approximately 165,000 stalks per acre. It, however, contains little leafy material. This has been a productive field in 1951 although considerable movement of soil has occurred under atmospheric winds.

Soil Unit: 4331   Soil Type: Dalhart fine sandy loam   Erosion: R

Soil Surface:

Mechanical composition - - - - 80.6% sand; 9.2% silt; 10.2% clay
Residue: sorghum stubble- - - 874 lbs. per acre
Ridge roughness equivalent - - 4.32 inches
Soil material < 0.42 mm. - - - 89.2%
Soil eroded by tunnel- - - - - 21.4 tons per acre

Surface and Cover Condition:

Fair

SITE 7

TINSLEY FARM (North field) (Sec. 36 - T3S - R33E), RooseveltnCounty, New Mexico.

April 9, 1952. Broom corn stubble cover resulting from very uneven stand with stubble varying in height ffom 4 inches to 2 feet and averaging about 10 inches. The stand is poor, averaging approximately 87,000 stalks per acre. The soil is somewhat heavier than that of the south field and cultivation appears to have pulverized the soil to a much lesser degree.

Soil Unit: 4331   Soil Type: Dalhart fine sandy loam (shallow phase)   Erosion: R

Soil Surface:
- Mechanical composition - - - - 75.1% sand; 11.2% silt; 13.7% clay
- Residue: Broom corn stubble - 650 lbs. per acre
- Ridge roughness equivalent - - 3.83 inches
- Soil material < 0.42 mm. - - - 70.1%
- Soil eroded by tunnel- - - - - 9.8 tons per acre

Surface and Cover Condition:
Poor

SITE 8

VINZANT FARM (Sec. 31 - T3S - R34E), Roosevelt County, New Mexico

April 9, 1952. The field contains residue from a 1951 growth of rowed sudan grass which has been combined at an approximate 10-inch height for seed. The stand is extremely heavy with approximately 435,000 stalks per acre and, further, the residue contains much leafy material. This appears to have been a successful crop in 1951 and has provided fair surface protection from spring winds.

Soil Unit: 4331 Soil Type: Dalhart fine sandy loam Erosion: R

Soil Surface:
Mechanical composition - - - - 77.7% sand; 9.0% silt; 13.3% clay
Residue: sudan grass stubble - 845 lbs. per acre
Ridge roughness equivalent - - 4.70 inches
Soil material < 0.42 mm. - - - 71.3%
Soil eroded by tunnel- - - - - 2.6 tons per acre

Surface and Cover Condition:
Fair

SITE 9

FIELDS FARM (Sec. 6 - T4S - R34E), Roosevelt County, New Mexico

April 10, 1952. Field in wheat in 1951 and listed in spring of 1952 to control flowing. Only a small amount of wheat residue remains on the surface of the field. Control is dependent upon the clods exposed on the surface of ridges and the trapping capacity of the furrows which are oriented in an east-west direction.

Soil Unit: 4331   Soil Type: Dalhart fine sandy loam   Erosion: R

Soil Surface:
- Mechanical composition - - - - 76.2% sand; 10.3% silt; 13.5% clay
- Residue: wheat straw- - - - - 155 lbs. per acre
- Ridge roughness equivalent - - 10.10 inches
- Soil material < 0.42 mm. - - - 61.8%
- Soil eroded by tunnel- - - - - 2.2 tons per acre

Surface and Cover Condition:
Fair

SITE 10

ELLIOTT FARM (South field) (Sec. 19 - T2N - R34E), Curry County, New Mexico

April 14, 1952. Sorghum stubble from 1951 sorghum crop harvested to a height of 6-7 inches. Active erosion has been experienced and the field has been chiseled diagonally to the row direction to control excessive movement. The diagonal chiseling has somewhat reduced the density of stubble remaining on the surface. This area was plowed to a depth of 12 inches in 1949.

Soil Unit: 4331 Soil Type: Dalhart loamy fine sand or sandy loam Erosion: R

Soil Surface:
- Mechanical composition - - - - 82.6% sand; 7.1% silt; 10.3% clay
- Residue: sorghum stubble- - - 245 lbs. per acre
- Ridge roughness equivalent - - 2.54 inches
- Soil material < 0.42 mm. - - - 82.0%
- Soil eroded by tunnel- - - - - 24.4 tons per acre

Surface and Cover Condition:
Poor

SITE 11

ELLIOTT FARM (North field) (Sec. 19 - T2N - R3rE), Curry County, New Mexico

April 14, 1952. Sorghum stubble from 1951 sorghum crop cut at 9-10 inch height. Chiseled diagonal to row to control drifting. Large clods brought to the surface by chiseling operation are too large and isolated to be effective. The wind tends to flow around and erode sand adjacent to their sides and to undermine them.

Soil Unit: 4331   Soil Type: Dalhart fine sandy loam   Erosion: R

Soil Surface:
Mechanical composition - - - - 83.3% sand; 4.4% silt; 12.3% clay
Residue: sorghum stubble- - - 640 lbs. per acre
Ridge roughness equivalent - - 4.65 inches
Soil material < 0.42 mm. - - - 68.4%
Soil eroded by tunnel- - - - - 21.4 tons per acre

Surface and Cover Condition:
Poor

SITE 12

STEPHENSON FARM (Sec. 3 - T1S - R35E), Roosevelt County, New Mexico

April 15, 1952. A high-lime field of relatively low productivity but well managed under prevailing conditions. Sorghum made too-little growth for combining and the heads were utilized by a short period of grazing with cattle. The remaining stubble is 10-12 inches high and very leafy. The stand is fairly good comprising about 195,000 stalks per acre. Some accumulations of drifting material from surrounding fields have occurred in the spring of 1952.

Soil Unit: 43L3k   Soil Type: Arch loamy sand or sandy loam   Erosion: R

Soil Surface:
- Mechanical composition - - - - 83.6% sand; 7.2% silt; 9.2% clay
- Residue: sorghum stubble- - - 715 lbs. per acre
- Ridge roughness equivalent - - 5.80 inches
- Soil material $<$ 0.42 mm. - - - 90.1%
- Soil eroded by tunnel- - - - - 21.9 tons per acre

Surface and Cover Condition:
Fair

SITE 13

WIVEL FARM (Sec. 4 - T2S - R34E), Roosevelt County, New Mexico

April 15, 1952. An eroded high-lime area from which approximately 2 inches of soil have been removed during the spring months. Lag material of lime granules has accumulated at the surface. Growth of broom corn has been meager as indicated by the relatively small quantity of residue.

Soil Unit: 43L3k   Soil Type: Arch loamy sand or sandy loam   Erosion: SLRR

Soil Surface:
- Mechanical composition - - - - 81.7% sand; 5.2% silt; 13.1% clay
- Residue: broom corn stubble - 400 lbs. per acre
- Ridge roughness equivalent - - 1.97 innhes
- Soil material < 0.42 mm. - - - 78.1%
- Soil eroded by tunnel- - - - - 21.2 tons per acre

Surface and Cover Condition:
Poor

SITE 14

NEAR FARM (Sec. 2 - T2S - R34E), Roosevelt County, New Mexico

April 16, 1952. A field on which sorghum has been contour drilled in 1951. While little harvest was attained, an excellent protective cover of stubble 12-14 inches high is present on the field. The stalks present average about 240,000 per acre and contain much leafy material.

Soil Unit: 43L2k Soil Type: Arch loamy sand Erosion: S

Soil Surface:
Mechanical composition - - - - 79.5% sand; 10.1% silt; 10.4% clay
Residue: sorghum stubble- - -1220 lbs. per acre
Ridge roughness equivalent - - 6.33 inches
Soil material < 0.42 mm. - - - 81.1%
Soil eroded by tunnel- - - - - 1.5 tons per acre

Surface and Cover Condition:
Good

SITE 15

FREEMAN FARM (Sec. 34 - T1S - R34E), Roosevelt County, New Mexico

April 15, 1952. Field of 1951 sorghum cut 3 to 4 inches high on an irrigated limey soil. The sorghum rows have been ridged by cultivation and provide a fairly rough surface to winds blowing normal to the row direction. While short, the stubble is extremely dense and averages about 650,000 stalks per acre. Very poor protection is afforded from winds blowing south-north in the direction of the rows and considerable removal of soil has occurred from the field.

Soil Unit: 43L2k   Soil Type: Portales sandy loam   Erosion: R

Soil Surface:

Mechanical composition - - - - 82.0% sand; 9.0% silt; 9.0% clay
Residue: sorghum stubble- - - 725 lbs. per acre
Ridge roughness equivalent --- 5.40 inches
Soil material < 0.42 mm. - - - 85.0%
Soil eroded by tunnel- - - - - 5.8 tons per acre

Surface and Cover Condition:
Fair

SITE 16

STANFORD FARM (Sec. 13 - T3S - R34E), Roosevelt County, New Mexico

April 10, 1952. An excellent cover of sorghum stubble on fine sand. This field contained the maximum weight of sorghum residue of any field tested. While the residue is only 7-8 inches high, its extreme leafiness makes it very effective in limiting the movement of sand between rows. The number of sorghum stalks is equivalent to 265,000 per acre. The field was deep-plowed several years ago.

Soil Unit: 5331   Soil Type: Dalhart loamy fine sand   Erosion: R

Soil Surface:
- Mechanical composition - - - - 86.1% sand; 3.4% silt; 10.5% clay
- Residue: sorghum stubble- - -1510 lbs. per acre
- Ridge roughness equivalent - - 8.27 inches
- Soil material $<$ 0.42 mm. - - - 87.3%
- Soil eroded by tunnel- - - - - 7.7 tons per acre

Surface and Cover Condition:
Fair

SITE 17

WIDNER FARM (Sec. 35 - T1S - R31E), Roosevelt County, New Mexico

April 7, 1952. A field of fine sand drilled to sorghum in 1950 and to wheat in 1951. Neither crop was productive. The field was listed to control drifting in the spring of 1952. Sand from adjacent fields and farms has filled the space between lister ridges. The surface presented at the time of tests was erodible in the extreme. This condition demonstrates the interdependence of one field or farm on another and the need for group action to alleviate soil drifting problems.

Soil Unit: 5331 Soil Type: Dalhart loamy fine sand Erosion: S

Soil Surface:
- Mechanical composition - - - - 89.9% sand; 1.2% silt; 8.9% clay
- Residue: wheat and sorghum- - 127 lbs. per acre
- Ridge roughness equivalent - - 3.47 inches
- Soil material $<$ 0.42 mm. - - - 97.5%
- Soil eroded by tunnel- - - - - 230.0 tons per acre

Surface and Cover Condition:
Poor

SITE 18

MOORE FARM (Sec. 14 - T1S - R34E), Roosevelt County, New Mexico

April 7, 1952. Sorghum drilled in 1951 on land broken from sod the previous year. Small amounts of yucca and grass residue are present. The growth of sorghum has been unsatisfactory and the rows are barely discernible. Much shifting of sand has occurred in the field. It is questionable that this land should be utilized for cultivated crops.

Soil Unit: 5331 Soil Type: Amarillo loamy sand Erosion: R

Soil Surface:
- Mechanical composition - - - - 86.2% sand; 4.4% silt; 9.4% clay
- Residue: sorghum stubble, Yucca and grass- - - 423 lbs. per acre
- Ridge roughness equivalent - - 2.42 inches
- Soil material < 0.42 mm. - - - 87.7%
- Soil eroded by tunnel- - - - - 89.8 tons per acre

Surface and Cover Condition:
Poor

SITE 19

BETTS FARM (Sec. 7 - T1S - R34E), Roosevelt County, New Mexico

April 7, 1952. A sandy field which has been farmed for many years. Large drifts of sand along field boundaries and roads make entrance to the field difficult. Sorghum planted in 1951 was a failure and a scattering of Johnson grass provides the only cover. Under current climatic conditions this land is a liability.

Soil Unit: 5331   Soil Type: Amarillo loamy sand   Erosion: SL

Soil Surface:
Mechanical composition - - - - 84.5% sand; 4.4% silt; 11.1% clay
Residue: annual weeds - - - - 311 lbs. per acre
Ridge roughness equivalent - - 1.96 inches
Soil material < 0.42 - - - - - 97.1%
Soil eroded by tunnel- - - - - 125.5 tons per acre

Surface and Cover Condition:
Poor